THE ROYAL AERONAUTICAL SOCIETY

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THE ROYAL AERONAUTICAL SOCIETY

A meeting of the Society was held at the Royal Society of Arts, John Street, Adelphi, W.C.2, on Thursday, October 25th, 1934, Lieut.-Colonel J. T. C. Moore-Brabazon (President) in the chair.

The PRESIDENT: He had to try and do a thing which the chairman so often had to do, namely, introduce somebody who did not require an introduction, one of the very distinguished Fellows of the Society, Mr. E. F. Relf, who had been many years in the draughty environment of wind tunnels. It was impossible to mention the words " wind tunnel " without associating the subject with Mr. Relf, who had been engaged on this work at the National Physical Laboratory for no less a period than since 1912. In his lecture that evening, however, Mr. Relf would confine his remarks to the compressed air tunnel.

The following paper was then read:—

RESULTS FROM THE COMPRESSED AIR TUNNEL

BY

ERNEST F. RELF, A.R.C.Sc., F.R.Ae.S.

Introduction

The Compressed Air Wind Tunnel has now been in more or less regular use for a little over a year, during which time some interesting results have been accumulated. While these results are not yet by any means complete enough to enable an exhaustive study of scale effect to be made, they are nevertheless of sufficient extent to throw light on several points in respect to scale effect which have hitherto been somewhat obscure, and in particular to show more clearly the relative effects of scale and turbulence on the important phenomenon of the maximum lift of aerofoils.

It may be well to review briefly the history of the development of the Compressed Air Tunnel and to give a very short account of the construction of the tunnel at the N.P.L. and of the preliminary work associated with its special measuring apparatus, as no mention of these matters has yet been made in the Society's publications.

The idea of using a wind tunnel working in a compressed gas, so as to compensate for low speed and small scale by a corresponding diminution of the kinematic viscosity of the working fluid, was first put forward by M. Margoulis in 1920. He proposed the use of carbon dioxide, since this gas has the lowest kinematic viscosity at a given pressure. The handling of large quantities of carbon dioxide was obviously not a simple matter, and the practical interpreta-

tion of M. Margoulis' idea, both in America and in England, took the more convenient form of the use of compressed air, the pressure being increased sufficiently to make up for the difference of viscosity. The first tunnel of this type to be built was the Variable Density Tunnel at Langley Field, constructed in 1922. The results which soon came to hand from this tunnel confirmed that scale effects were in many cases of very considerable magnitude, and far outside the accuracy with which modern aircraft design was possible. Some question was raised in this country as to the direct applicability of the V.D.T. results to full scale, and as to the possible effects of turbulence in vitiating such an application, and it was decided to ask the American authorities to test three models having wings of different section, on which there was a great deal of full scale and ordinary model data in this country. The results of these tests were quite definite in showing that the V.D.T. gave results much closer to full scale than did the ordinary atmospheric tunnel, especially in the case of maximum lift coefficient. Largely on the strength of this evidence, it was decided that a well-equipped aerodynamic laboratory should possess a tunnel of this type, in which scale effect could be studied in detail, and provision was accordingly made for one to be built at the National Physical Laboratory. Model experiments were at once started at the Laboratory in order to determine the best design of tunnel to be placed inside a cylindrical pressure vessel of specified size. It was felt that the velocity distribution then achieved in the V.D.T. was hardly good enough, and this led to a design having a considerable contraction of area just before the working section was reached, as in Prandtl's open jet tunnel at Göttingen. A great deal of model work was carried out to settle the best form for the air passages, the best means of supporting the tunnel structure without interfering with the air flow, and the largest jet diameter which could be used without impairing the flow characteristics. During this period, various firms were approached with regard to the manufacture of the pressure vessel to enclose the tunnel, and all the matters concerned were discussed by a special Sub-Committee of the Aeronautical Research Committee appointed for the purpose. Actual construction of the tunnel was started in 1929, and in the summer of 1930 erection at the Laboratory was commenced. As it was necessary to erect in the open, and complete the building afterwards, the tunnel was not ready for a trial until the summer of 1931, when it was tested under a hydraulic pressure 50 per cent. in excess of the working pressure of 25 atmospheres. During the following winter, the velocity and direction of the air current were thoroughly explored in order to make certain that the model predictions had been fulfilled, and much time was spent by the makers of the tunnel in attempts to reduce leakage at the joints of the shell and at the gland on the propeller shaft. The main aerodynamic balance was installed during the summer months of 1932. This is necessarily a very elaborate piece of apparatus and it was not until the following winter that all the details were completed and the balance calibrated satisfactorily. Tests were undertaken of several wooden aerofoils that had been prepared, in order to establish the best technique of such measurements, and to determine the corrections that had to be applied for interference and parasitic drag of the supports. This work occupied a considerable time, as it was imperative to carry it out very carefully over the whole range of Reynolds number in order to establish the corrections, which had of necessity to be measured as small differences. During this time a few experiments were also made on the drag of cylinders and spheres, with a view to throwing light on the turbulence characteristics of the tunnel, and much time was spent on perfecting the methods of measuring wind speed in the tunnel. These various activities occupied considerably longer than was at first anticipated and it was not until the early summer of 1933 that it was felt that the whole of the apparatus was entirely satisfactory, and that a serious start could be made upon the researches for which the tunnel was intended. It is now considered that the time spent on the perfection and adjustment of the very special measuring apparatus of the tunnel was thoroughly justified. During

the first year of regular running there has been practically no trouble at all of an instrumental nature in spite of the complexity of the apparatus. Moreover, it has been definitely established that the instrumental accuracy is at least as high, both in the measurement of wind speed and aerodynamic forces, as it is in an ordinary atmospheric tunnel. Considering that the range of forces and pressures to be covered is 25 times as great as in the ordinary tunnel, the achievement of this accuracy over the whole extended range is very gratifying.

The above account is presented as in some sense an apology for the fact that this lecture has been twice postponed on account of the development of the tunnel and its apparatus having taken much longer than was at first anticipated. It was, however, our policy to make very sure that everything connected with the tunnel was as good and as accurate as human ingenuity could make it, since it was felt from the outset that results from a British tunnel of this type would be taken as standard by British designers, and it was accordingly undesirable to present any results short of the best attainable. Moreover, as will appear later in the lecture, the recent researches of Professor von Kàrmàn and others on the effects of turbulence on maximum lift made it impossible to publish any results until a reasonable assurance was forthcoming that they were not in serious error as a result of turbulence in the air stream of the tunnel.

Methods of Measurement

It is not intended here to attempt a complete description of the special methods of measurement adopted in the Compressed Air Tunnel, as this alone would provide enough material for a whole paper, but it is felt that a brief outline of such methods should precede the presentation of the results that have so far been obtained. The general principle of all the measurements is the balancing of forces by the electro-magnetic attraction between coils of wire carrying a current, instead of by weights moved electrically as in the V.D.T. This principle is familiar in the current balances designed by Lord Kelvin for the establishment of the unit of current, but it is interesting to note that Clerk Maxwell attributes to Joule the first suggestion that such electro-magnetic reactions could be used to measure forces.* A few calculations made in 1928 convinced the present author that the method could be satisfactorily applied to the Compressed Air Tunnel balance, and moreover that the whole range of forces, up to some 1,000lbs., could be covered without the use of an exorbitant weight of copper in the coils. At the same time he devised an adaptation of the alternating current induction bridge which enabled the swing of the balance to be indicated at a distance by the swing of a galvanometer needle, thereby dispensing entirely with the necessity of being able to see the apparatus in the tunnel through peep-holes, and enabling the whole of the balance operation and reading to be conducted at a control table outside the tunnel. The balance as finally designed consists essentially of a ring frame surrounding the free jet of the tunnel, and enclosed in a shield to protect it from stray air currents outside the jet. The model under test is attached rigidly to this frame by any convenient system of wiring or spindles and the aerodynamic forces so transferred to the frame. The frame can oscillate as a balance about three parallel axes in turn. The first axis passes through a convenient reference point on the model (*e.g.*, the centre of gravity position of a complete machine), the second axis is five inches downstream, and the third ten inches vertically above the first. A single set of electro-magnetic coils at the top of the frame serves to measure the couple on the frame about each of the three axes, the change from one axis to another being effected by cam mechanism driven by three-phase induction motors (to avoid sparking). A single balance indicator serves also for the three measurements. The couple about the first axis gives directly the pitching moment on the model, while the

* "Electricity and Magnetism," Clerk Maxwell, Vol. 11, p. 371.

couples about the other two axes, corrected for the pitching moment, give the lift and drag respectively. The leverages have been so arranged that the calculations involve only multiplication by small whole numbers. The angle of incidence of the model is varied by a specially designed motor and gearing operated from the control table, and simple indicators on the table show the observer at any moment what incidence is set, and which of the three axes of measurement is in operation.

The method of support adopted for aerofoil models and for complete model aeroplanes with square wing tips is novel. It was found from tests in one of the 7ft. tunnels that spindles of considerable diameter placed close to the leading edge at the wing tip and parallel to the span produce an almost negligible interference effect on the aerofoil drag, although the interference effects have long been known to be appreciable when such spindles are placed at about one-third of the chord back from the leading edge. Aerofoils have accordingly been supported in the C.A.T. by two such spindles, guarded right up to the aerofoil tips by slightly conical guard tubes, and arranged so that the aerofoil can rotate about the ends of the spindles for incidence adjustment. A streamline wire from the trailing edge at the centre of the span completes the suspension. This wire is also guarded by a streamline tube except for a few inches near the aerofoil, and its upper end is moved up and down by the incidence motor to change the angle of the model to the wind. The corrections due to the supports were determined on two very different aerofoil sections at all angles of incidence and at all Reynolds numbers by the following method. The aerofoil was supported entirely by wires, and measurements were made with and without the side spindles and their guard tubes in position. The difference gives the interference of the side supports and this was found to be very small under all conditions. The parasitic drag of the exposed part of the rear wire was obtained by duplicating it and its guard at some little distance from the centre of the span. At this stage of experimenting, results on several aerofoils with the tunnel at atmospheric pressure were compared with those obtained in a 7ft. tunnel at the Royal Aircraft Establishment. The agreement found was practically perfect on both lift and drag, except at maximum lift, where the C.A.T. results were always a little lower than those from the 7ft. tunnel, a difference which is in accordance with Glauert's analysis of the effect of tunnel constraint (R. & M. 1566). The above agreement was considered very satisfactory especially as the C.A.T. balance was operating under conditions where the *maximum* force measured was only 1/25 of the maximum for which it was designed.

The method adopted for the measurement of wind speed deserves a word of mention. In essence it is that used in all tunnels, viz., the calibration of a pressure difference between two convenient points of the tunnel circuit against a standard pitot tube. The only difference is in the method of measuring the pressures. These are determined by two special manometers installed inside the tunnel. Each manometer consists essentially of a U-tube mounted on a simple balance, so that the amount of liquid transferred by the applied pressure from one limb of the tube to the other can be weighed by electric coils similar to those of the main balance. It may also be mentioned here that all the balance fulcra, both on the main aerodynamic balance and on the pressure manometers, are formed by crossed springs instead of knife edges or points, and that the accuracy which has been attained over a very extended range of forces is largely attributed to the extreme freedom of these spring fulcra from friction.

Results

Turning now to the results which have been obtained, these are mainly concerned with the aerodynamic behaviour of aerofoils and of a model of the Parnall Parasol monoplane, and with the comparison of results on the latter with full scale data on the machine in flight. There are, however, a few interesting measurements of other kinds and these will be mentioned first.

Sphere Drag

The curves of Fig. 1 show the drag coefficient of spheres against Reynolds number in the critical range for various tunnels. The tests in the C.A.T. were made with the sphere supported on wires and it is likely that the wires caused the critical fall of drag to occur at a lower Reynolds number than it would have done had the sphere been held by a rear spindle. They must therefore be regarded as giving an inferior limit for the " turbulence number " of the tunnel. It will be seen that these results indicate that the C.A.T. is a little less turbulent than the standard N.P.L. type of closed atmospheric tunnel, but much more turbulent than von Kàrmàn's tunnel at Pasadena. The V.D.T. at Langley Field is shown to be more turbulent than any of the others. The Pasadena

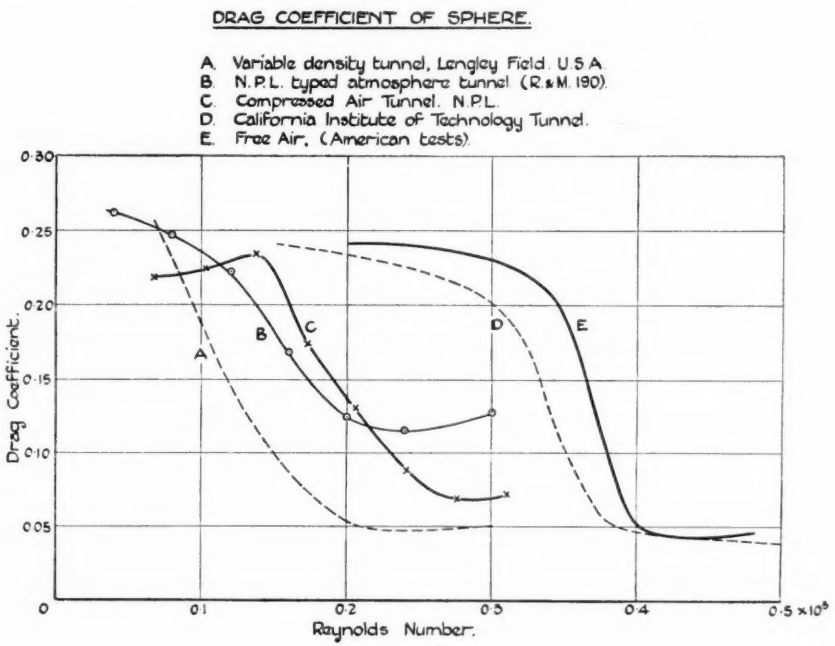

FIG. 1.

curve for free air is given for comparison with the various tunnel results. The C.A.T. results apply to the tunnel at atmospheric pressure. No attempt has yet been made to establish the turbulence at high Reynolds numbers by the use of spheres, as this would be very difficult on account of the small diameter of sphere which must be used and the difficulty of supporting it without introducing a very large correction for parasitic drag. Moreover, as will be apparent later, it seems doubtful whether the critical number for spheres is always a reliable guide as to the effect of turbulence on other phenomena, such as the maximum lift of aerofoils.

The Drag of Circular Cylinders

Fig. 2 shows some drag measurements made on circular cylinders of three different diameters. The cylinders were 4ft. in length and were mounted between the two side spindles used for aerofoil tests, circular plates being attached to the

spindle guards so as to preserve approximately two-dimensional flow conditions up to the ends of the cylinder. No great accuracy is attached to these results, as they were made at a time when the speed calibration of the tunnel had not been satisfactorily established. They are, however, of some interest, as they appear to show that there is a turbulence effect depending on the relation of the scale of turbulence to the cylinder diameter. Thus, while the results for any one cylinder fall on a unique curve at all Reynolds numbers, the results for each cylinder give a different curve. Moreover, the rate of fall of drag through the critical region is much less for the smallest cylinder than for the largest. No attempt is made to explain these results at present. It is intended to repeat them more accurately at some future time when more important work is completed. It is interesting to note that at very high Reynolds numbers the drag coefficient appears to be reaching a steady value at about 0.3, a fact which is of some importance to structural engineers in assessing wind loads.

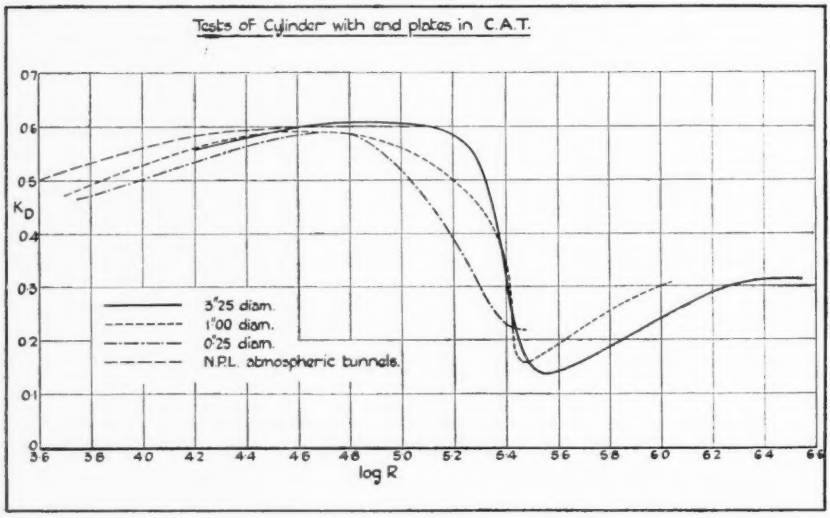

FIG. 2.

Effect of Townend Rings on the Drag of a Body with an Air-cooled Engine

These tests, the results of which are given in Fig. 3, were made because it was suspected that there might be a scale effect on the uncowled engine cylinders, giving a lower drag at full scale Reynolds number than would be predicted by an ordinary model test. If this were so, an explanation would be provided of the statement which has often been heard that the Townend ring does not always give the predicted improvement of performance. It is apparent from the C.A.T. tests, which were made with a very detailed model of the engine, that no such scale effect exists on the model tested. There is the usual slight fall of drag coefficient in the low Reynolds number range of ordinary tunnels, but this occurs both with and without the ring, and at higher Reynolds numbers the drag coefficient is almost constant. Apart, therefore, from any effects due to airscrew slipstream, the tests suggest that the drag reduction predicted for a Townend ring in an ordinary tunnel should be achieved on the full scale machine.

Aerofoil Tests—Introductory

As mentioned earlier, tests were made on wooden aerofoils to determine the corrections due to the method of support adopted. During these tests it became very obvious that wood was not a suitable material even for thick aerofoils. While it is strong enough for all except the thinnest sections, its low modulus of elasticity lead to large corrections to the mean incidence on account of the dis-

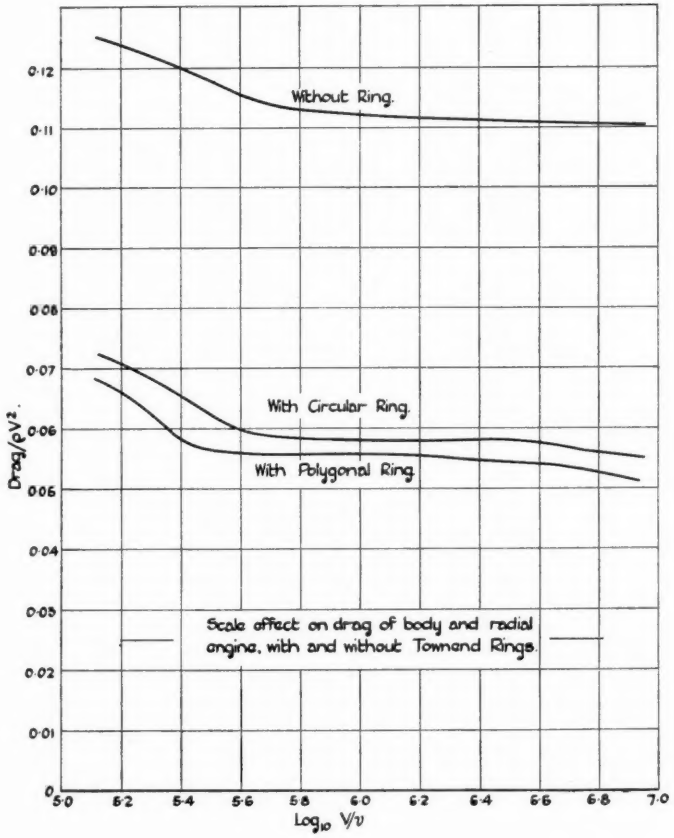

FIG. 3.

tortion under load. This did not matter in the tests to determine the support corrections, since the distortion was the same for the two measurements whose difference gave the correction, and none of the corrections varied rapidly with incidence. For standard aerofoil tests, however, it was evident that the models must be made of metal. Aluminium has been used for all such tests, but even with this metal the deflection corrections at the higher Reynolds numbers are sufficiently great to make their determination important, especially with the thinner sections. A technique has accordingly been developed for loading the aerofoils with shot-bags when supported in the tunnel, the incidence changes being measured with a sensitive bubble inclinometer. Fortunately it is found that with

the particular points of support adopted the deflection under load causes a small incidence change which is almost the same at all points of the span, thereby greatly simplifying the application of the correction. The correction, however, depends appreciably on the position of the centre of pressure, and the method which has been employed is to determine the centre of pressure by a test at atmospheric pressure in the tunnel and to use this data in the application of the load for the deflection correction, on the grounds that the slight variation of C.P. with Reynolds number is not great enough to affect the deflection correction appreciably. If aerofoils of less than about 8 per cent. thickness/chord ratio are to be tested, it will be necessary to use steel instead of aluminium, so as to keep the deflection corrections within desirable limits, and a special free-machining steel is at present being tried for the manufacture of a thin symmetrical section (N.A.C.A. 0012) which has been selected by the American authorities as a desirable aerofoil for a detailed comparison of results obtained in the C.A.T. with those from the V.D.T.

A few notes on the routine of aerofoil testing may be of interest. The pressure in the tunnel does not remain exactly constant during a test. At high pressures there is still a little leakage at the joints of the tunnel shell, and the pressure falls during a test. At lower pressures, where the leakage is very small, the pressure tends to rise a little on account of the rise of temperature of the air, due to the energy dissipated in the tunnel fan. The procedure adopted is to set the electric current in the balance coils of the tunnel speed manometer, so that balance of the manometer corresponds to a suitable value of ρV^2, and to maintain this value of ρV^2 constant by variation of tunnel speed throughout the test. The result is a slight variation of Reynolds number during the test, but as there is never more than a slow change in the values of the force coefficients with Reynolds number, this is of no great consequence, and a mean value of Reynolds number is usually amply accurate. The temperature of the air in the tunnel, which is needed for the determination of the Reynolds number, is obtained by the use of a direct reading resistance thermometer.

As regards the time taken in tests of this nature, it may be remarked that a complete determination of lift, drag and pitching moment at 2° intervals of incidence from zero lift to well above the stall occupies about an hour and a half. As this involves some 36 observations, 12 about each axis, together with zero readings, and includes the time to change from one axis of measurement to another and to change the incidence, it will be seen that the actual time taken to effect an individual adjustment of the balance to equilibrium is quite short, and probably shorter than that for an ordinary tunnel balance using weights and a rider.

Tests of Clark YH Aerofoil with Flaps

These tests, the results of which are presented in Figs. 4, 5 and 6, were made in the spring of 1933, using a wooden aerofoil with flaps formed by bolting angle sections of suitable form along its length. These angles stiffened the aerofoil appreciably and rendered the deflection corrections less serious, even under the increased lifts obtained. The results, though they have not the same accuracy as later standard aerofoil tests, are exceedingly interesting in showing the effect of increased Reynolds number on flaps of the Zap and Schrenk types. The Zap flap was selected from certain American results, the large chord of the flap being chosen because it gave the highest lift recorded in the atmospheric tunnel tests with a very sharp fall at the stall. It was desired to ascertain whether this very peaky lift curve would still be reproduced under full scale conditions, or whether the sharp top would be smoothed out at a lower maximum value as sometimes occurs with high lift aerofoils. The lift results of Fig. 4 show quite definitely that at a Reynolds number of 3.9×10^6, which is rather higher than the stalling condition of an aeroplane of moderate size, the lift curve

continues to rise to a considerably higher maximum than obtains in the atmospheric tunnel, while the drop of lift at the stall is even more sudden. The results for a 10 per cent. Schrenk flap given in Fig. 5 show a similar result, but with a considerably lower maximum lift coefficient. In both cases it was found that the extreme limit of lift could not always be reached, and in particular that when the angle of incidence was reduced slowly from a value above the stall, the lift often did not rise to the unstalled curve until an incidence of one or two degrees below that of the absolute maximum lift was reached. This phenomenon of a loop in

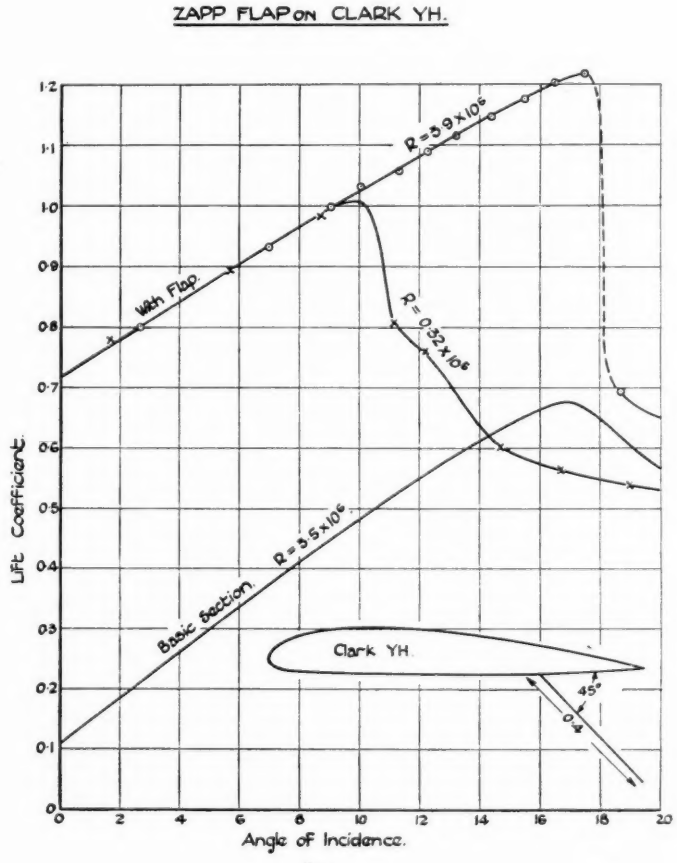

FIG. 4.

the lift curve during a cycle of incidence changes is of course familiar in tests of some aerofoils in ordinary wind tunnels, but it is believed that this is the first time it has been shown to occur also at full scale Reynolds number. The practical significance of these lift measurements is that a machine must be designed to land at an incidence a little below the absolute maximum, so as to avoid the chance of a disturbance throwing the lift on to the lower curve and so causing a heavy landing. As the maximum lift with flaps is so high, this sacrifice can be

made while still leaving a very great increase of lift over that of the plain aerofoil. The effects of the two flaps on drag are shown in Fig. 6, and it will be seen that the drag increase for the Zap is about twice that for the Schrenk. It appears probable that the amount given by the Schrenk flap would be ample for landing purposes, so that if the Zap type is used, the flap chord could be made very much less than 0.4 chord.

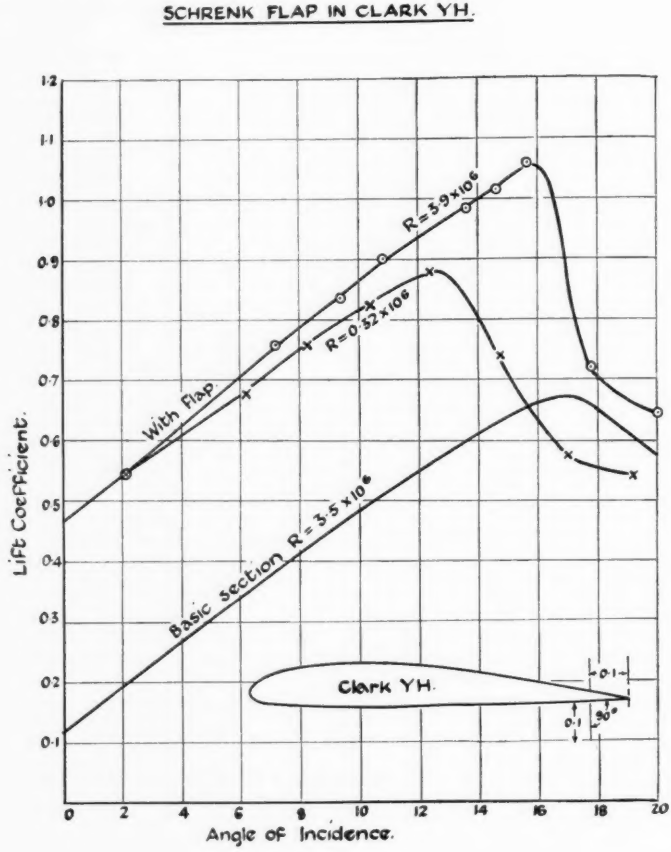

FIG. 5.

Standard Aerofoil Tests

At the time when the C.A.T. was constructed, the only wind tunnel data available on aerofoil sections at full scale Reynolds numbers were those from the Variable Density Tunnel at Langley Field, and these data had proved of very great value to designers. There has, however, never been a detailed published comparison between the results of the V.D.T. and those of actual flight tests, although the statement has been made in American publications that such comparisons were satisfactory. This statement may be true as regards aerodynamic data applicable to normal flight, but it must be accepted with some reserve as regards maximum lift, since the values of maximum lift obtained

in the three different modifications of the V.D.T. on the same aerofoil vary much more than the probable error of either model or full scale measurement. In view of these facts, it was felt that a very careful comparison of results in the C.A.T. with flight tests was essential, especially at maximum lift, and accordingly one series of aerofoils chosen for test was that to be used on the Parasol monoplane at the R.A.E., a machine specially designed for the comparison of different wing sections in flight. This series comprises R.A.F. 28, 38 and 48 and a tapered aerofoil constructed with these sections. It was also

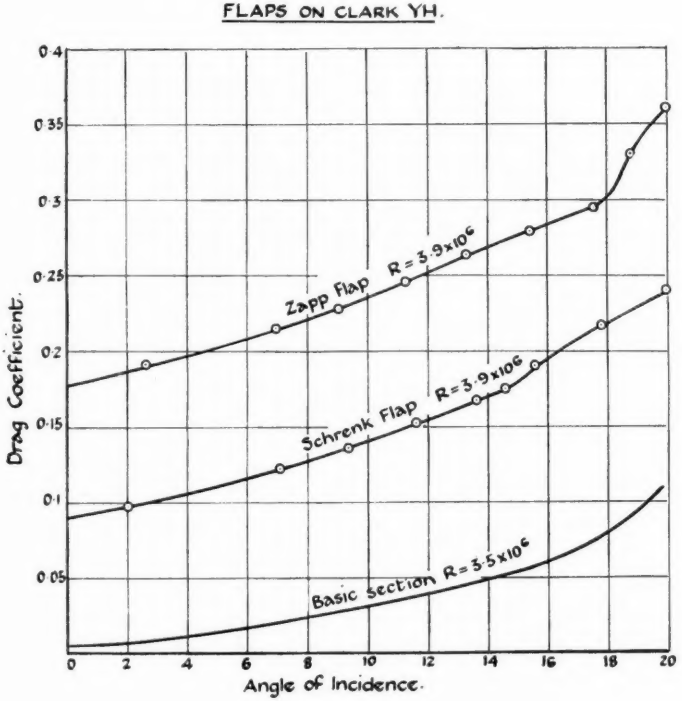

FIG. 6.

felt that it would be inadvisable to embark upon a long series of systematic aerofoil tests before a comparison with flight tests and with the V.D.T. was available. A very great number of sections has been tested in the American tunnel and there would be no advantage in repeating such work unless there were reason to suspect that the two tunnels gave divergent results. It was therefore decided that for the moment it would be sufficient to test a few well-known sections, and those chosen in addition to the R.A.F. 28 series mentioned above were R.A.F. 34, Clark YH and Göttingen 387; the last mainly because it was known that the nature of its maximum lift variation with Reynolds number was different from that of the other sections. These six aerofoils, made in aluminium, have now been tested over nearly the whole range of Reynolds number available in the Compressed Air Tunnel and provide a collection of aerofoil data of considerable value. It is impossible to present all the results in this paper (they will shortly be published in the Reports and Memoranda of the

Aeronautical Research Committee), but a few diagrams showing the general nature of the results are given. Fig. 7 shows the group of lift curves obtained for Clark YH, when the Reynolds number varies from 0.3×10^6 to nearly 7×10^6. It illustrates very well the high degree of instrumental accuracy that has been obtained in the C.A.T. measurements, the curves for the different Reynolds numbers falling very well into a series with scarcely a dissentient observation. It may be remarked here that the aerofoils had a chord of 8 inches and a span of 4ft., and that the lowest Reynolds number of 0.3×10^6 corresponds with an atmospheric tunnel test at about 80 ft./sec. on this chord. The value of Reynolds number for the stalling speed of a machine of average size is of the order of 3×10^6.

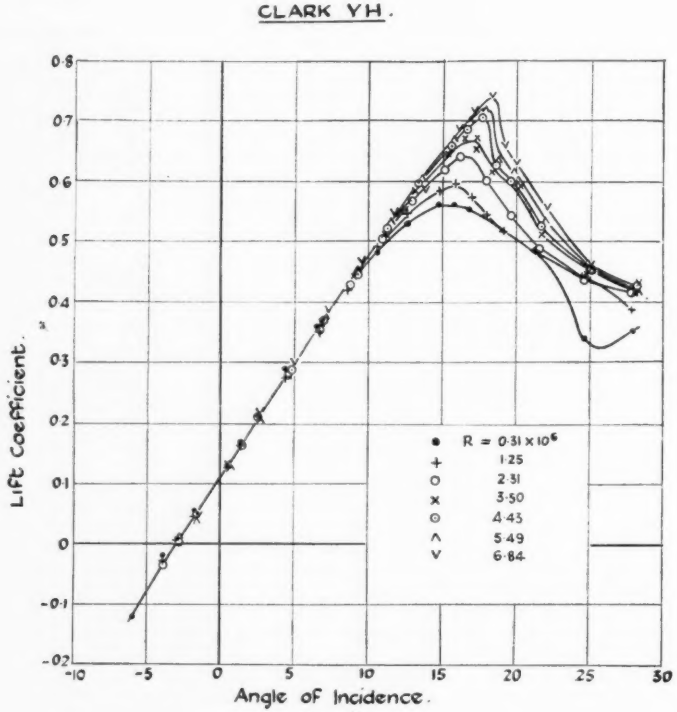

FIG. 7.

The next two figures give an analysis for all the aerofoils of the two important characteristics, maximum lift and minimum profile drag. From Fig. 8 it will be seen that, speaking roughly, all the aerofoils except Göttingen 387 show the same kind of variation of maximum lift with Reynolds number, and that with all of these there is a very considerable increase, even at a Reynolds number of 3×10^6 over the values obtained in ordinary wind tunnels. The behaviour of Göttingen 387 is different, the maximum lift falling as Reynolds number rises up to a value of about 4×10^6, and then rising slightly as the Reynolds number is further increased. This behaviour is probably characteristic of an aerofoil having a considerable thickness and also a fairly large centre line camber. The nearest approach to this type of section among the other aerofoils is R.A.F. 48, and

this certainly shows a less rapid rise of maximum lift than the remainder. It is interesting to notice how all the curves tend to a value not very far removed from 0.7 at a Reynolds number of 5×10^6. In Fig. 9 the minimum profile drag coefficient has been calculated and divided by two so as to express it in the form of a skin friction coefficient. The curves of laminar and turbulent skin friction for a flat plate are given on the diagram for comparison. An interesting feature of the results is that the profile drags of all the aerofoils except Göttingen 387 lie on one curve almost within the degree of accuracy of the experiments. This accuracy is of course not very high, as the measured drags themselves are small and a large fraction of them has been subtracted as induced drag containing

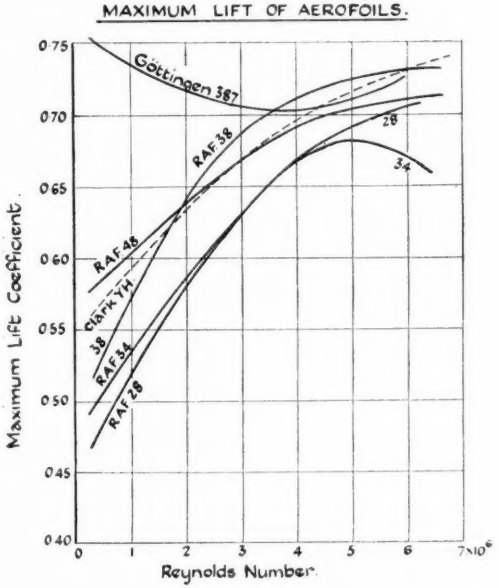

FIG. 8.

the experimental errors of the lift measurements. There is no doubt, however, of the tendency of the drags at medium values of Reynolds numbers to lie well below the turbulent skin friction curve, and to approach this curve closely only at the highest Reynolds numbers attained. In fact, the points lie very closely on the transition curve given by Gebers. These results have not been corrected for form drag, as this is unknown at any but possibly the lowest Reynolds number; if so corrected they would lie lower still on the diagram. The values at $R = 0.3 \times 10^6$ (atmospheric pressure) lie higher than might have been expected and close to the turbulent curve, but this is also the case with results at this Reynolds number from other tunnels. It is suggested that these profile drag results may be explained in general along the following lines. In the first place it is known from Fage's pressure plotting experiments on a series of large-chord Joukowski aerofoils* that the form drag diminishes considerably as the Reynolds number rises, a result which would be expected from the fact that the boundary layer gets thinner and that the general flow approximates more closely to potential flow as Reynolds number is increased. On the other hand, if the tunnel flow is

* R. & M. 1241.

not too turbulent, it would be expected that there would be an appreciable portion of the chord over which the boundary layer was laminar, the amount diminishing with rising Reynolds number. It is thus apparent that at low Reynolds number the drags would tend to lie on the laminar skin friction curve, were it not for a large form drag which raises them in this case nearly to the turbulent curve. As Reynolds number increases the skin friction tends to rise as a larger portion of the boundary layer becomes turbulent, but tends to fall owing to the decrease of form drag. At first the latter tendency is the stronger and the drag curve falls, but later the form drag becomes small and the results tend to follow the transition curve characteristic of a flat plate, reaching the completely turbulent curve at a very high Reynolds number. It is thought that at the highest Reynolds number of the present tests the form drag must have become very small and that practically the whole drag is skin friction. For a flat plate the transi-

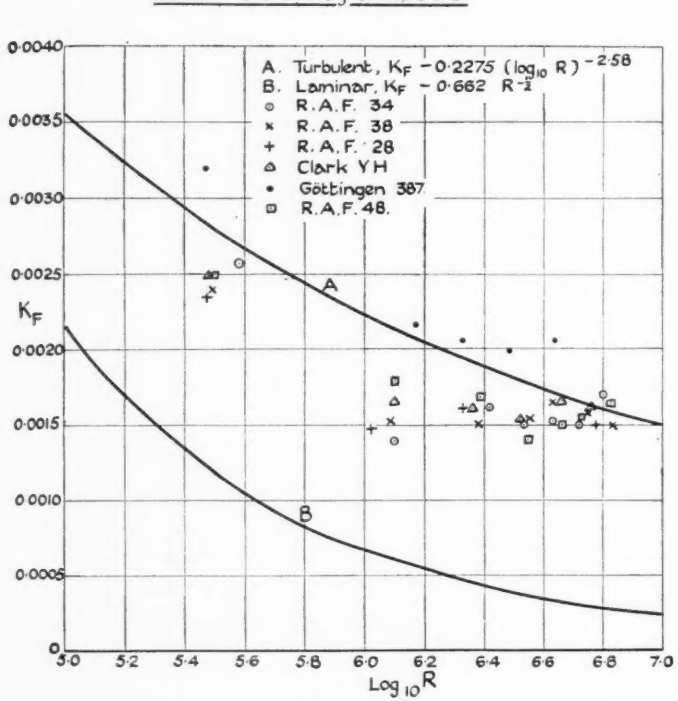

FIG. 9.

tion from laminar to turbulent boundary layer flow would occur at about half an inch from the leading edge at this Reynolds number, a fact which lends colour to the view that nearly all the aerofoil has a turbulent boundary layer. The drag would then be expected to approximate closely to the turbulent curve if there were no form drag, and the experimental fact that it does so seems to indicate that the form drag must be very small. It would be interesting to measure the form drag in this condition by pressure plotting the aerofoil, but this experiment would be very difficult to carry out. Even in an atmospheric tunnel a very large

number of pressure points are needed to define the form drag with any accuracy, as is shown by Fage's experiments mentioned above, and in the C.A.T. at high pressures where the form drag is suspected to be only a small fraction of that in an ordinary tunnel, the experimental difficulties of its accurate determination would be very greatly increased.

A very important practical deduction from the present results is that for all good aerofoils less than some 13 or 14 per cent. thick the profile drag under top speed conditions can be taken directly from the turbulent skin friction curve, and the appropriate induced drag added. It would appear that this process is likely to be as accurate for design purposes as a direct test in the C.A.T. and a good deal better than any attempt to extrapolate from total drag tests in an atmospheric wind tunnel. This conclusion is probably not true for thicker sections, especially with a large centre line camber, as is indicated by the Göttingen 387 results, which lie decidedly above all the rest over the whole range of Reynolds number. It is hoped to throw more light on this point at a later date by a few tests on much thicker sections, up to at least 20 per cent. of the chord.

Effect of Tunnel Turbulence on the Measurements

It has been known for a long time that turbulence in the airstream of a wind tunnel can very greatly affect certain kinds of measurement, *e.g.*, the drag of streamline bodies. As long ago as 1910* the author conducted tests of the drag of an airship form in a free tunnel and behind screens designed to augment the turbulence, and found that very large changes of drag were produced especially when the screens were near the body. These tests, made long before the theory of boundary layer flow was understood in this country, were intended to show whether it was likely or not that atmospheric turbulence would affect airship drag. We now know that no such deduction could legitimately be drawn from model tests at so low a Reynolds number. The explanation of the results of these tests came later, when the theory of the boundary layer was understood. Briefly the explanation, now well known, is that as Reynolds number increases the boundary layer becomes turbulent nearer the nose of the model and as turbulent flow in the layer leads to higher skin friction than laminar flow, the total drag rises. Turbulence in the airstream tends to produce an earlier transition by disturbing the boundary layer, and thus gives rise to a higher drag than would be observed in non-turbulent flow. It has even longer been known that in cases of so-called critical flow, *e.g.*, that round a sphere or a cylinder at the stage where the drag coefficient falls rapidly, turbulence created by an upstream disturbance or by a tiny excrescence suitably placed on the body causes the fall of drag to occur at a lower Reynolds number. The connection between this phenomenon and the boundary layer flow is complicated, but has been very carefully explored by a number of experimenters. It is not necessary to discuss the results they have obtained here, but merely to note the two forms in which the effects of airstream turbulence are manifested, (1) increase of drag due to the earlier onset of boundary layer turbulence, and (2) alteration of the conditions of breakaway of flow in a critical region. The first has an obvious bearing on the drag of all bodies of good form, while the second has an equally obvious application to the drag of bluff bodies and to the important phenomenon of the maximum lift of aerofoils. These facts concerning turbulence profoundly affect the application of model results. In the ordinary atmospheric wind tunnel they introduce an additional complication into any scheme of extrapolation to full scale, and it has not been uncommon in recent years to hear the apparently paradoxical suggestion that turbulence effects should be eliminated by making the stream as turbulent as possible. The idea is that with a very turbulent stream the boundary layer is at once rendered almost entirely turbulent, and extrapolation

* R. & M. 597.

on the known law of turbulent skin friction is possible, whereas in an ordinary tunnel with little turbulence, most results lie in the transition region, and any attempt at a logical rule for extrapolation is impossible.

The bearing of all this on results obtained in a Compressed Air Tunnel is evident; the full scale Reynolds number is reached so that scale effect proper no longer need be considered, but is there still left an effect of the turbulence of the stream which may be different from that appropriate to flight in the earth's atmosphere? If so, the direct application of C.A.T. results to the design of aircraft is not possible unless an allowance can be made for turbulence effects. The question is thus one of fundamental importance in the use of this type of wind tunnel.

A very interesting and careful investigation of this kind was recently made under the direction of Prof. Th. von Kàrmàn at the Pasadena Laboratory in California. There is here a wind tunnel whose turbulence, as indicated by the critical curve of sphere drag is exceedingly low, and von Kàrmàn found that values of maximum lift found in this tunnel over a range of Reynolds numbers up to about 1.5×10^6 could not be extrapolated to include the values found in the V.D.T. on the same sections at a Reynolds number just over 3×10^6. Suspecting turbulence to be the cause of the discrepancy he introduced more and more turbulence into the tunnel by means of screens and showed quite conclusively that at a certain degree of turbulence the maximum lift results became consistent with those of the V.D.T. This was the first definite proof that even at full scale Reynolds numbers turbulence can have marked effects on maximum lift, and the question at once arose—what is the turbulence in the free air? Kàrmàn endeavoured to answer this question by measuring the drag of a sphere carried by an aeroplane and was led to the conclusion that turbulence in the air, even in bad weather or near the ground, was exceedingly small, and certainly less than in any wind tunnel. This does not mean that the disturbed velocity components are small, or in other words that vigorous eddies do not exist, but rather that the scale of such eddies is large and they affect a small body as changes of relative velocity, and not as influences which disturb the boundary layer.

These results of von Kàrmàn's investigations were of a very disturbing nature, as they seemed to indicate that a considerable tunnel turbulence effect on maximum lift was a thing to be expected. It was accordingly realised that this matter must be very thoroughly explored before results from the C.A.T. could be published with any assurance that they would apply reasonably accurately to full scale flight. There are two ways in which some light can be thrown on this point and both have been explored to some extent. In the first place the tunnel turbulence can be varied and the effects studied, but unfortunately it is difficult, if not impossible, to *reduce* the turbulence, and this appeared to be necessary if the free air condition was to be reached. The second method is the direct comparison of tunnel results with full scale tests, a means whereby the existence of any large turbulence effects must be revealed, but which is unlikely by itself to provide an analysis of them if they exist. The results which have so far been obtained by each of the above methods will now be described.

Effect of Turbulence Screens on Maximum Lift

Two turbulence screens were used in the C.A.T. They consisted of vertical strips $\frac{1}{4}$ inch wide spaced in one screen 3 inches apart and in the other $1\frac{1}{2}$ inches apart. The screens were placed 21 inches or 2.6 chords ahead of the aerofoil. A very detailed velocity exploration behind the screens was conducted with the tunnel at atmospheric pressure, and tests of an aerofoil showed that when the measured mean speed behind the screen was used in calculating the coefficients, the slope of the lift curve was not measurably affected by the turbulence. It

was assumed that this would also be true at high Reynolds numbers, and the slope of the lift curve with a screen was adjusted to agree with that obtained without the screen. It was realised that this method is not strictly correct, but as fairly large effects of turbulence on maximum lift were found it was considered that it could not fail to reveal the general nature of such effects. The alternative would have been a velocity exploration behind the screens with the tunnel under pressure, and this would have involved the construction of a considerable amount of additional apparatus. The results obtained on two aerofoils, R.A.F. 28 and Göttingen 387, are shown in Fig. 10. These aerofoils were chosen on account of the dissimilarity of the variation of maximum lift with Reynolds number, and the effects of the screens were found also to be markedly

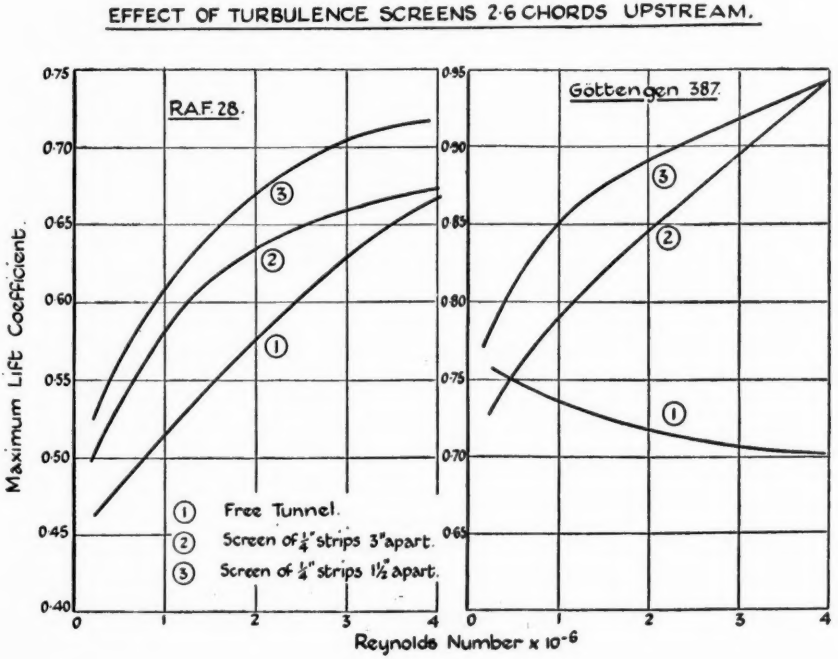
EFFECT OF TURBULENCE SCREENS 2·6 CHORDS UPSTREAM.
R.A.F. 28.
Göttingen 387.
Maximum Lift Coefficient.
Reynolds Number x 10⁻⁶
① Free Tunnel.
② Screen of ¼" strips 3" apart.
③ Screen of ¼" strips 1½ apart.

FIG. 10.

different in the two cases. With R.A.F. 28, speaking roughly, the maximum lift is increased at all Reynolds numbers by about the same amount, and the effect increases with increase of turbulence. With Göttingen 387, however, a very different result is obtained. At low Reynolds numbers the effect of the turbulence is comparatively small and is apparently not proportional to the turbulence; at high Reynolds numbers the effect is exceedingly large and apparently independent of the degree of turbulence. The latter effect suggests that in this condition the aerofoil lift may be critical at a certain turbulence greater than that of the free tunnel but less than that created by the wider-spaced screen. In the case of R.A.F. 28 the curve of maximum lift in a non-turbulent tunnel might be expected to lie somewhat below that for the C.A.T. without screens over the whole range of Reynolds number, but in the case of Göttingen 387 the results do not suggest such a likelihood. The phenomenon is obviously complicated and depends greatly

on the shape of the section. To explore it thoroughly it would be necessary to reduce the tunnel turbulence to as low a value as possible, and as this would be a very large undertaking, it was decided that comparisons with full scale should first be made, since these might show that the free tunnel values were so little in error that the residual effect of the free tunnel turbulence could be regarded as small. The results of these full scale comparisons, as far as yet available, are given in the next section of the paper, but before passing to them a word may be said as to the effects of the turbulence screens on minimum drag. These results are exhibited in Fig. 11 for the same two aerofoils. It will at once be seen that the effects are not so marked as those on maximum lift, and that they

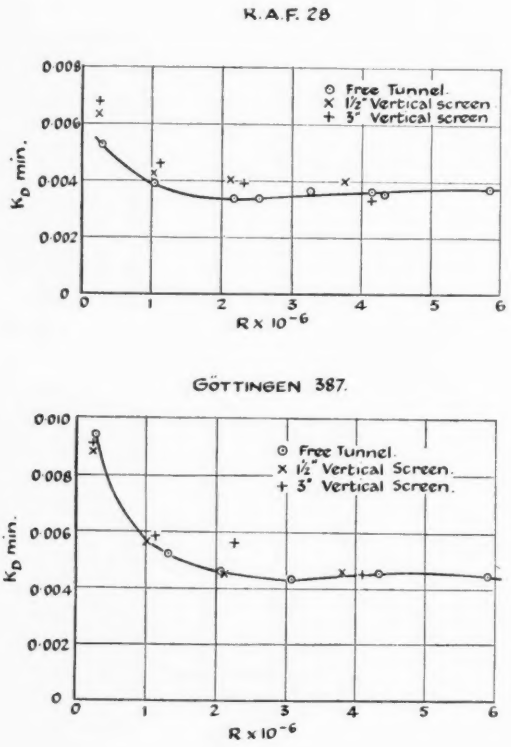

FIG 11.

do not differ in nature on the two aerofoils. At the higher Reynolds numbers the effects are very small, and this is in accordance with the idea that under these conditions the boundary layer tends to be nearly all turbulent, so that additional disturbances due to tunnel turbulence would not be expected to produce any appreciable additional effect. It is relevant to note here that profile drags from the V.D.T. tend to be somewhat higher than those from the C.A.T. This would appear to be a turbulence effect, the V.D.T. being known from sphere tests to be very turbulent, but it seems scarcely likely that it is as turbulent as the C.A.T. with the closer-meshed screen. It is hoped that the comparison tests on N.A.C.A. 0012, mentioned earlier in the lecture, will shed more light on this

matter. This section is a symmetrical one, and therefore specially convenient for the study of minimum drag.

Comparison with Full Scale Results—Maximum Lift

The provision of the Parnall Parasol monoplane at the R.A.E. offered an exceptional opportunity for the comparison of C.A.T. results with those obtained in actual flight. This machine has its wing mounted on a dynamometer, so that the reaction between the wing and the body can be directly measured. It is thus possible to obtain two distinct comparisons, one on the wing forces alone and another on the total forces on the aeroplane as determined by the normal methods of performance testing. Of these, the latter is by far the simpler from the point of view of tunnel technique, since the former involves the separate support of wing and body in the tunnel, forces being measured on the wing only. The overall comparison has therefore been made first, and has so far been concerned mainly with maximum lift, since the tunnel turbulence tests have shown that it is here that the greatest effects of turbulence are likely to be manifested. The model of the Parasol monoplane has been very carefully constructed. The wing is of aluminium, the body being made of hard wood and containing a special form of electric motor which moves the elevators so that the model may be trimmed in the tunnel precisely as the machine is trimmed in flight. The tail surfaces are made in metal. All reasonable detail on the machine has been copied on the model, the only exception which may prove of some importance being the unavoidable roughnesses of the full scale construction, *e.g.*, the sag and taping of the wing fabric. The model, having square wing tips, is supported in the tunnel exactly in the same way as a simple aerofoil, and the body can be easily attached to any standard aerofoil, thereby converting it to a model of the machine with that section. As mentioned above, it was considered that the maximum lift was the most important comparison to make from the point of view of possible turbulence effects. For this measurement certain simplifications have been made in the model tests. In the first place the complication of trimming the elevators in the tunnel was avoided by setting them and the tailplane at the angles actually used in flight at the stall. Further, the airscrew was not present on the model, comparison being made with full scale results at zero thrust. Three wing sections have so far been tested in this way, viz., R.A.F. 28, R.A.F. 34 and R.A.F. 38. The results for these three sections are given in Fig. 12 in the form of a plotting of maximum lift coefficient against Reynolds number. In this figure the full curves are obtained on the model, over the whole range of Reynolds number from that of an ordinary 7ft. tunnel to a value exceeding considerably that of the full scale machine at its stalling speed. The crosses are points obtained from a simple aerofoil test. The short horizontal lines in the neighbourhood of 3×10^6 are the observed full scale results on the whole machine. These short lines represent approximately the small range of Reynolds number over which the full scale results extended, as this quantity varies slightly with the altitude at which the test is made, and the numerical value of the lift coefficient is taken from a mean curve obtained from many observations. It will be convenient to deal first with R.A.F. 34 and R.A.F. 38, which appear on the right of the diagram. Here it will be seen that the agreement with full scale is practically perfect, the differences being of the order of one or two per cent. at the most. The case of R.A.F. 28 is peculiar and very interesting. In the wind tunnel, dual values, as shown on the diagram, were frequently obtained at Reynolds numbers in the neighbourhood of the full scale value, while the flight tests indicate quite definitely even three quasi-stable values of the maximum lift coefficient. The lower two of these are near those of the tunnel, but the highest was never detected in the model tests. It may be remarked here that this uncertainty of maximum lift was also shown up in the flight tests by the fact that it was exceedingly difficult to hold the machine steady

at the stall, the tendency to drop a wing suddenly being very marked. The conclusion to be drawn from the above comparisons is that when the maximum lift is definite the tunnel gives an exceedingly close approximation to the full scale result, and that in the case of a section like R.A.F. 28 with an indefinite maximum, both model and full scale show the existence of more than one condition of flow near the stall. In these cases then, it can only be concluded that the turbulence of the tunnel airstream is not great enough seriously to affect maximum lift determination. It is, of course, impossible to generalise this conclusion on so little data, and in particular a comparison on a section like Göttingen 387, which is differently affected by large increments of tunnel turbulence, would be very enlightening. Such a comparison will be made by providing the Parasol machine with a wing of this section.

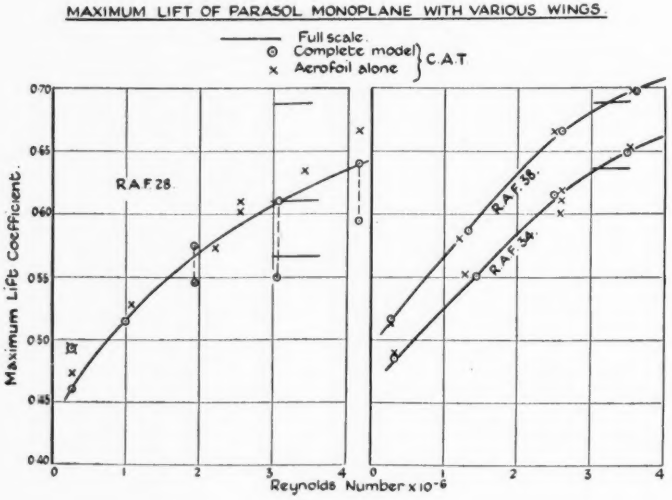

FIG. 12.

It is interesting, in passing, to note that the maximum lifts obtained on the complete model in the C.A.T. are very nearly the same as those on the aerofoils alone, while the maximum wing lifts measured full scale on the dynamometer are appreciably lower. It would appear that with the Parasol monoplane type of machine there is a diminution of lift produced by the presence of the body below the wing, which is almost neutralised by the lift on the body itself. The forthcoming tunnel tests on the wing alone in the presence of the body, will give further information on this point.

The fact that the maximum lift on the whole machine is so nearly equal to that on the wing alone led the author to make the very interesting, though somewhat tentative comparison illustrated by Fig. 13. There is as yet no data on the same section from the V.D.T. and the C.A.T., and for which full scale confirmation exists. One of the sections used by Kàrmàn, viz., N.A.C.A. 2412, is however, very similar to R.A.F. 38, but a little thinner. By making an interpolation between R.A.F. 38 and R.A.F. 28 a section is found which has a very close resemblance to N.A.C.A. 2412. Such an interpolation has been made between the curves for maximum lift of the two sections and gives the full curve of the figure. The points plotted as circles are obtained from Kàrmàn's test of N.A.C.A. 2412 in the Pasadena tunnel. The square point

is an interpolation of full scale results on the Parasol monoplane, again between R.A.F. 38 and R.A.F. 28, while the single point at the top of the figure is from the V.D.T., on N.A.C.A. 2412. The comparison suggests that as far as effects on maximum lift are concerned the C.A.T. appears to be no more turbulent than the Pasadena tunnel, in spite of the fact that the critical number for a sphere test is considerably lower. It was this comparison which prompted the suggestion made earlier in the paper that the effect of turbulence on the critical region of sphere drag may not be a reliable guide to its effects on other critical aerodynamic phenomena. The very high value given by the V.D.T. is strikingly apparent, and suggests that this tunnel, in its present form, has too high a degree of turbulence and gives maximum lifts well above those of the

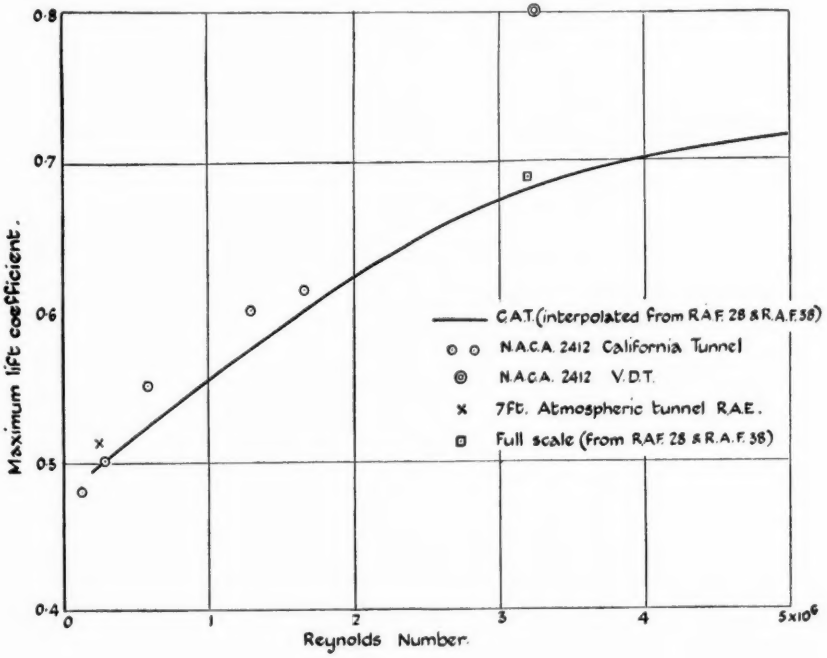

FIG. 13.

full scale. The single cross at the left hand of the figure is a result from the R.A.E. in an ordinary 7ft. tunnel. All such results lie a little above the curves given by the C.A.T., but the correction for tunnel effect on maximum lift proposed by Glauert brings them into close agreement. The whole of the evidence seems to indicate that the turbulence in a well designed return flow tunnel having a reasonable contraction ratio is not of a kind that seriously affects maximum lift, and that lift results from such tunnels may be expected to be close approximations to those which would be obtained in free air at the same Reynolds number.

Comparison with Full Scale—Drag

There is not as yet enough data from the C.A.T. on the wing drag and total drag of the Parasol model to enable a proper comparison with the full scale tests to be made, but Fig. 14 has been given to show the present state of

knowledge on this matter. This diagram gives lift plotted against drag for the R.A.F. 28 section. The full scale curve (C) is that of wing drag on the machine, while the C.A.T. curve (B) is that for an aerofoil alone. The curve of induced drag (A) is also plotted. It will be seen that there is a considerable and almost constant difference of profile drag between the model and full scale results. It is the explanation of this difference that is now engaging attention, and there are several facts which may together well account for it all. In the first place, the presence of the body is known to reduce wing lift, and if this occurs, as is likely, by a distortion of the lift grading, a certain measure of extra induced drag on the wing may be introduced. It is not thought that this effect can be great, as it would be expected to lead to an increasing difference of drag as the lift increases

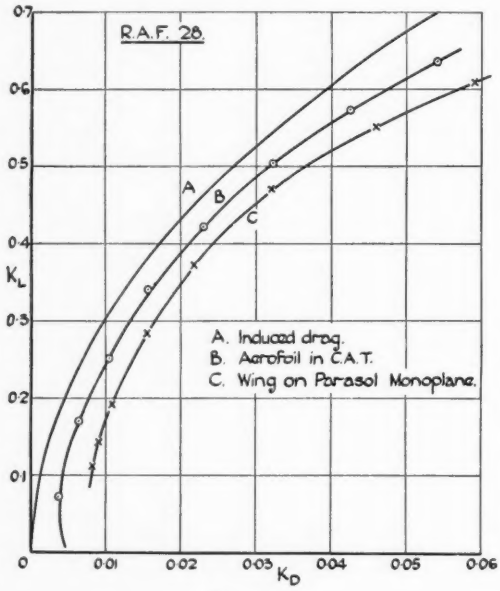

FIG. 14.

and not to a nearly constant difference, as observed. More likely causes are to be found in the presence of excrescences on the full scale wing, and the interference of struts on the wing. In the model test a plain aerofoil was used, whereas on the full scale there are such things as the aileron gap, aileron operating levers, pitot static tube, and general wing roughness, all of which may be expected to contribute to an increase of profile drag. Moreover, the wing struts are inclined at a comparatively small angle to the span of the wing, and there may be an interference effect which has not been rightly estimated in correcting the full scale results for strut drag. The obvious experiment to make is to repeat the full scale test as exactly as possible in the tunnel, and this is now being done. All the minor excrescences enumerated above will be represented on the model, except the surface roughness, and the wing struts will be cut at such a point that the fraction of their drag transmitted to the wing is the same as that conditioned by the full scale measuring mechanism. As most of the strut-wing interference must be due to the upper end of the struts, this will be correctly represented in the model test. The comparison will be made between the model

observations and the uncorrected full scale ones. If this leads to reasonable agreement it will be fair to deduce that the tunnel is giving a correct full scale value of drag, and also that if the full scale wings could be made as smooth as the model, there would, apart from unavoidable strut interference, be an appreciable saving of drag. If, however, there is still a disagreement, further investigations will have to be devised to discover its origin.

Conclusion

As previously stated, it is not pretended that there is as yet sufficient data to enable it to be said that the Compressed Air Tunnel is an infallible guide to full scale conditions, but from the evidence which at present exists it appears exceedingly unlikely that any serious discrepancies will be found. It is abundantly clear that whatever small differences may be produced by failure exactly to observe the law of similarity, in other words, by turbulence differences, the C.A.T. gives results which are a far better guide to design than any which can be obtained in atmospheric tunnels. It is confidently hoped that future work in the tunnel will establish a better aerodynamic basis of design than could possibly have been achieved without a tunnel of this kind, not only in connection with performance, but also in relation to other aerodynamic considerations where scale effect may be important. It is also hoped that the provision of a body of data over the whole range of Reynolds number, and known by full scale tests to be directly applicable to free air conditions, will throw much light on the mechanism of scale effects in general, and enable a better use to be made of data obtained from ordinary wind tunnels.

Finally, the author desires to express his indebtedness to the Aeronautical Research Committee for permission to give this lecture and to use a number of results which are as yet unpublished.

Discussion

Dr. N. A. V. Piercy, F.R.Ae.S. (East London College): The meeting had been privileged to listen to one of the most important papers before the Society in recent years. If he might say so, it removed a load from the minds of those forced to express opinions about aeronautics who had been in a perilous position; Mr. Relf's infallible wind tunnel might have proved so much to be wrong. But upon the whole the experiments now reported had been kind to preconceived ideas and theories. Personally, he was particularly interested in the experiments on minimum profile drag. There had been a sporting chance that the theory which Mr. Relf's work seemed so clearly to support might not have held at all, and that all aerofoils, except very thin ones, might have joined forces with Göttingen 387. To designers it was a great relief to know that something like flat plate theory actually applied to aerofoils through a useful range of thickness, as had been hoped. The present limit of 13 or 14 per cent. thickness was unduly small for monoplane design; if a few aerofoils of even 16 per cent. thickness could be found in the same category an important step would have been achieved. Supposing Mr. Relf's fundamental work to continue at the present rate and having regard to the field already covered, the speaker hoped that the tunnel might be free soon to test some extraordinary wings—he meant thoroughly unfamiliar shapes—in the hope of discovering useful scale effects which could not at present be anticipated.

Mr. H. E. Wimperis, F.R.Ae.S. (Director of Scientific Research, Air Ministry, Vice-President of the Society): He expressed the view that the author had been very wise not to hurry into an explanation of what had been done with the compressed air tunnel. It was not the first tunnel of its kind; the one in America was older and ample experience with that had shown the difficulty of interpreting some of the results. The Americans had got over these

troubles, but they evidently had encountered a degree of turbulence which made it difficult to know exactly how much value could be put on the results for maximum lift. Mr. Relf had been able to show that the compressed air tunnel gave results which agreed exceedingly well with free flight conditions. This was especially notable in the case of the later sections that he had mentioned, the R.A.F. 34 and 38; as regards R.A.F. 28, the curious changes in the maximum lift agreed with the research work carried out by the Cambridge University Air Squadron, with Professor Jones, at Duxford, who also had worked on this section. The Cambridge workers had clearly shown that more than one condition of flight was possible. One of the things shown by Mr. Relf's lecture was that we were now beginning to get some idea of the interconnection between turbulence and Reynolds number. At the moment, of course, we did not by any means know all about this, but we were beginning to understand it especially in reference to the more or less streamline forms which we were now aiming to employ in aircraft, but when it came to bluff forms—cylinders and spheres—the thing was not quite so clear. In that connection he was going to put a question of a popular character to Mr. Relf and ask him to explain why the surface of a golf ball was roughened, because at first sight it might be imagined that a smooth surface should give a lower resistance to flight. It might be explained that the roughening of the surface increased turbulence and that with increased turbulence one reached sooner the critical Reynolds number at which the flow regime changed altogether and the drag became lower. Was that Mr. Relf's explanation? If it was, he personally regarded it as not really satisfactory, because it did not afford a physical explanation of what was going on.

Major F. M. GREEN (Fellow): The paper was of first importance and he felt it would help to clear up a misunderstanding between the scientific workers in aeronautics and practical aircraft designers. Wind tunnels had been working for a very long time—about 24 years—and in the beginning designers naturally turned to wind tunnels to obtain the data required for designing aeroplanes of particular forms. Unfortunately, they found the predictions they made from wind tunnel results very often led them astray. Mr. Relf had now told them the reasons for that, but as these reasons were not known in the early days, that created some mistrust in wind tunnel work in general. The result had been that aircraft designers, unfortunately, were calculating performances in a way which was mostly unscientific but gave fairly good results. The method adopted was to split up the aeroplane into various components and to obtain the best available information about the resistance of each component. Then they adopted an empirical correction for the whole, which was generally a big one, and calculated the performance in that way. That did not work too badly whilst aeroplanes had a fairly high resistance, but the drag had been going down so rapidly that the method ceased to be practicable. He feared that he himself was guilty in a paper before the Society last year of using data obtained in that way in endeavouring to arrive at the economic speed of flight; as a result of Mr. Relf's work it was probable that the economic speed of flight would be increased appreciably. So far he had not had time to work out what it really meant, but at any rate, Mr. Relf in his present lecture had cleared up nearly all the difficulties in a manner which would help aircraft designers very much indeed to design good aeroplanes. There was one very important point which all aircraft designers should remember, namely, the necessity for making wind tunnel tests of models which were like the aeroplane, or conversely, the aeroplane should be like the wind tunnel model. That might sound a distinction without a difference, but in point of fact it was not, because we were all in the habit of making drawings of aircraft and then not making the aircraft precisely like the drawings. The model was made precisely like the drawings, but during manufacture little things crept into the design which might account for the difference in profile drag, as, for instance, in the R.A.F. 28 section. Aircraft designers

would be well advised in the future not to grumble because the models were not like the aircraft but to make perfectly certain that the aircraft were reasonably near the drawings and the model.

It was very comforting to know that the effective profile drag of wings could be reduced to as low a figure as 0.003 or a little higher, and this became more and more important as the drag was reduced on all the other parts of the aircraft. Finally, Major Green said he felt there was no doubt that on passenger aircraft at least the drag would be reduced to the skin friction drag plus the induced drag, plus the power required to cool the engine. It was to be hoped, however, that Mr. Relf would make further experiments which would help designers to reduce still more the power required to cool the engine.

Dr. W. D. Douglas, F.R.Ae.S. (Royal Aircraft Establishment): The lecturer had taken a very complicated subject and covered a very wide range in a remarkably lucid manner. In the development of the compressed air tunnel Mr. Relf had taken the rather crude American design, but by his ingenuity in balance design and apparatus he had done wonders. Everybody was very interested in the results that were being produced and those at Farnborough were very pleased to be co-operating with the author. It was mentioned in the paper that the profile drag on the Parasol wings tested was slightly in disagreement and these results were now being investigated. One point in which Farnborough was in agreement with Mr. Relf was that there was very little difference in profile drag with thicknesses up to 13 or 15 per cent. Previously there had been the impression that there was a considerable rise in profile drag with thickness.

Professor G. T. R. Hill, F.R.Ae.S. (University College, London University): It was no less than 22 years since he paid his first visit to the National Physical Laboratory and had the experience of sitting in one of the old wind tunnels in a wind at the then great speed of 40ft. per second. It was a long step from that time to the present and everybody would agree that very remarkable advances had been made for which a great deal of the credit was undoubtedly due to Mr. Relf, who had shown amazing mechanical ingenuity in solving the various problems which, in the design of a tunnel such as had been described, were very formidable.

Dealing with the actual results recorded in the paper, Professor Hill said it seemed to him that the modern pilot might well ask " What is maximum lift?" The work that had been done by Mr. Relf at the compressed air tunnel and the investigations which were going on at Cambridge at the present time under the direction of Professor Jones seemed to indicate that we were just beginning to understand that maximum lift on some aerofoils was by no means a definite point which could be plotted on a chart. When a result was obtained which apparently indicated that the maximum lift was a force which varied continuously with time, the whole problem appeared to become enormously complex; but what really mattered from the immediate practical aspect was, in his opinion, to try and find out what properties of aerofoils enabled us to produce an aeroplane which would land slowly. Was it any good having a very high maximum lift if that only persisted for a second or two and then changed, and might perhaps appear again for a few seconds, or was it better to be content with a maximum lift which was appreciably lower but yet steady, and, in particular, steady across the whole span? It seemed that if the maximum lift was varying continuously with time it was probably varying continuously all over the span. One could imagine the lift, appearing and disappearing, as it were, in lumps at different points on the wing. Certainly that was what it felt like on some aeroplanes when the stalling stage was reached.

In connection with minimum drag, Professor Hill stated that the very low results that have been obtained are of extreme interest, because when we get down to drag coefficients of 0.003 and 0.004 on a wing, a drop of 0.001 was a

big thing. In other words, before he had seen Mr. Relf's paper, he had had the idea that the minimum drag coefficient was possibly of the order of 0.004, and if that could really be reduced to something like 0.003, it was a very big percentage change. Judging from the last illustration shown by Mr. Relf, it appeared that we had not yet achieved that on the full scale. It had been pointed out, of course, that the problem was still being studied, but at the same time it seemed a little difficult to swallow the explanation which had been put forward tentatively, namely, that the additional drag was due to small excrescences, etc., on the actual aeroplane wings, coupled with the strut interference. These excrescences, however, did apparently double the minimum profile drag of the wing, and he was inclined to think that there was more in that which remained to be satisfactorily explained. So far, on the full scale, as far as he was aware, they had not succeeded in producing this very low minimum drag, but at the same time, Mr. Relf's experiments showed quite definitely that there was a very good hope of reducing it, and the important thing, of course, was to find out how to do this; was it to be by producing an extremely accurate wing contour, or by extreme smoothness of surface?

Another point was that now it had apparently been found out that all aerofoils of thin section and of medium thickness seemed to have the same minimum drag, it became very important to find out how much it was possible to thicken up an aerofoil before the drag began to rise unduly. The reason for that was obvious, since the thicker the wing, the more easy it was to accommodate a light wing structure within the contour. He felt that if that problem were explored results of very great value could be made quite rapidly available for the use of designers in the future.

Mr. W. O. Manning (Fellow and Member of Council): With reference to turbulence in the atmosphere, he gathered from the paper that this was formidable. Although the turbulence might be considerable at some distance from the ground, however, was it not probable that it might be very different near the ground?

Another matter was the actual roughness of the plane. In the case of certain American machines he had noticed it was the custom to put a glass-like finish to the wings. Did the author think that would be an advantage, because it would seem that if the roughness of the wing was small compared with the thickness of the boundary layer it could not affect the resistance, and if that were the case there would be the paradoxical result that the effect of wing roughness would be more serious at low speeds? But roughness might lead to the area of the low speed boundary layer being equal to that at high speeds.

Finally, Mr. Manning recalled a section known as T.64 which was used during the war, which was accused by several pilots of having separate stalling points.

Dr. H. Roxbee Cox, A.F.R.Ae.S. (Royal Aircraft Establishment): Mr. Relf had explained his interesting results so cleverly that he was tempted to remind him of an airship paradox which had been a puzzle to him for some years and which he thought had never been satisfactorily explained. Drag coefficients of airship models obtained in atmospheric tunnels had been used successfully to predict full-scale performances and, in the cases of some of the earlier airships, had agreed very well with drag coefficients obtained on the full scale in deceleration tests. He would like to have Mr. Relf's comments on this point, and wondered whether a " size effect " had to be taken into consideration, because the ratio of atmospheric eddy size to aircraft size was in the case of the airship so different from what it was in the case of the aeroplane.

Another point which interested him, said Dr. Cox, was in connection with the manner in which the model aerofoils in the C.A.T. tunnel were supported. He had been unable to understand why the incidence correction for torsional deformation under the air loading was nearly constant across the span, as Mr.

Relf had mentioned, and would welcome any further details which might explain this.

Dr. H. F. Winny, A.F.R.Ae.S. (East London College): With reference to the drag of circular cylinders, he called attention to the fact that Mr. Relf had shown in Fig. 2 that the smaller cylinders were affected more than the larger by turbulence in the air stream. Later in the paper the small effect on wing characteristics of the turbulence in the atmosphere was attributed to the smallness of the body compared with the scale of turbulence. It would be interesting if Mr. Relf could give some explanation of these two statements. It was also suggested in the paper that the drag of spheres might not be a criterion for the turbulence in the air stream. It seemed it was not a criterion for the effect of turbulence on lift coefficient, but might it not be that the lift coefficient was not affected much by a small increase in turbulence? Referring to the maximum lift coefficients shown in Fig. 8 which all approximate to 0.7 at full scale, the results from the V.D.T. indicate that for thinner sections, *e.g.*, $t/c=6$ per cent., the maximum lift coefficient would still remain considerably below 0.7 even at full scale.

Mr. Max M. Munk (*communicated*): The paper deals with a subject which lies closely to the writer's heart. That is the method to study the motion of free air by forcing a portion of that air into a tight container and studying it within. This seemingly far-fetched method occurred to the speaker after a talk with Mr. J. C. Hunsaker, in which the latter had pointed out the necessity for some new method. M. Margoulis was inspired to his very laudable efforts to sponsor this method in England by a letter from the speaker on the subject. Mr. Hunsaker, then with the U.S. Navy, took likewise to the novel method and made it possible to have constructed a compressed air tunnel at Langley Field, Va., U.S.A. So much for the history of compressed air tunnels.

Mr. Relf's paper gives full evidence of the fact that the N.P.L. is now to be envied for the possession of an excellent compressed air wind tunnel in charge of a crew who know well how to operate it. The tests reported on in that paper talk a loud and distinct language testifying to that end.

The paper reveals further a concern of the author about the turbulence of the tunnel; whether the same will be a cause of uncertainty of the quantitative results or not. He seems to see the chief purpose of the novel tunnel in directly giving a complete and exact answer to immediate design problems of aircraft builders. Methods should be devised, the author thinks, which eliminate any numerical discrepancy between test and flight by means of a simple routine arithmetical correction. He certainly wished Mr. Relf much success in that endeavour, but he did not think that could be done, nor should, and would rather wish to relieve him from that unnecessary anxiety.

It seemed to him that a wind tunnel was not a question-and-answer box; it is asking too much from a wind tunnel to relieve the designer entirely from aerodynamic studies, and this is really not its purpose. He knew quite well that the conception of a wind tunnel as a slot machine, which at the pressing of a button furnishes airplane dimensions, is quite widespread. Chiefly in the U.S., where there is a tendency to overdo everything, this delusive expectation has led to absurd conditions. There is now more money spent here annually for wind tunnels and the like than for experimental aircraft; in fact, the wind tunnel industry is larger than the airplane industry, with the outcome of said artificially boosted wind tunnelling in a pitiful disproportion to the money spent for it, the furtherance of aerodynamic science being at the same time almost wholly neglected as a consequence.

Ordinary 5 to 6ft. wind tunnels have their legitimate function for the assistance and guidance of the airplane designer in his work, and their costs are commensurate with the practical service they furnish. Even these wind tunnels are not indispensable; there are aeroplane factories of high standing without a

wind tunnel. The limitations of wind tunnels are indeed formidable, they are restricted to problems arising in straight even flight, which are the least serious problems, and just the ones that with least difficulties can be solved by flying. Indeed, the many thousands of miles flown every hour cannot be prevented from furnishing much necessary information. Practical wind tunnel results have to be finally checked in flight, and flight is the source of instruction which flows incessantly and is the natural gate to further practical knowledge. Wind tunnels are secondary. The uncertainty of wind tunnel results aggravates this argument.

He proposed and proposes the compressed air wind tunnel for a widely different purpose; that is to provide a tool for fundamental study of the physical laws of air motion, to serve the speculative scientist urged by philosophical curiosity and not urged by any necessity to produce a commercial product. Modern technics has been chiefly stimulated by that kind of scientific research, and that research is in the end much more profitable for the community than attacking immediate design problems by the brute force of endless series of routine measurements in an otherwise thoughtless manner. The compressed air wind tunnel is particularly suitable for such research directed to the study of the air friction and its effect; because this tunnel creates air motions under friction conditions not possible in ordinary wind tunnels. This air friction, however, and not the tunnel turbulence, is the key to further progress of aerodynamics. The influence of turbulence is accidental and secondary, that of friction dominating and the object of chief scientific interest. Friction is an inherent property of air, the turbulence they talked about is merely an experimental feature.

The whole scientific world looks to the British compressed air wind tunnel for progress in aerodynamics, and in that connection it is not very material whether the turbulence inside the tunnel is smaller or larger than that of the atmosphere. Even without turbulence the tunnel could not give quantitatively exact design directions, because in the nature of things that cannot be expected from small idealised models under entirely artificial flow conditions.

Reply to Discussion

He agreed with Dr. Piercy that the Compressed Air Tunnel should be used to test any extraordinary aerofoil sections which might be proposed, and certainly to investigate limiting cases such as very thick aerofoils, though he hoped it would not be necessary to test great numbers of sections as had been done in the Variable Density Tunnel in America. He also remarked that the general policy followed would be to use the Compressed Air Tunnel to explore any problem where ordinary tunnel results showed that scale effect was likely to be an important factor.

Mr. Wimperis mentioned the American data on maximum lift coefficients. The lecturer felt that the American authorities should have given some explanation of the differences obtained in their various modifications of the V.D.T. and a comparison with full scale. Maybe they were satisfied that they knew how to apply the V.D.T. results correctly, but they had not told us how to do it! As regards the question of golf balls, the lower critical speed of the rough ball would help to increase the range, but he thought the most important effect of roughness was to increase the lift on the ball due to spin and so give a higher trajectory.

The question of adding up the drag of parts of a machine was raised by Mr. Green. He agreed that though the Compressed Air Tunnel gave useful data on wings, bodies, etc., there still remained the question of putting these components together with the minimum possible interference drag, and he thought this kind of investigation was a proper use of the Compressed Air Tunnel in the future, when the basic data on parts was fully established. He also agreed that the low profile drags of the tunnel should be attainable in practice, but that

they might not be attained on account of roughness of construction. He instanced the rivet heads on the Douglas machine that competed in the Australia race and wondered how much they added to profile drag. Possibly the correct procedure was to make the wing absolutely smooth near the leading edge, but to ignore the small roughnesses nearer the trailing edge. This kind of investigation was better suited to a large wind tunnel than to the Compressed Air Tunnel on account of the difficulty of representing such small excrescences on a small model. Also the engine cooling problem mentioned by Mr. Green was essentially an investigation for a large tunnel, as cooling conditions could not be properly represented on a small model.

He thanked Dr. Douglas for his kind remarks on the ingenuity of the apparatus in the Compressed Air Tunnel. While he was ready to take credit for the electrical methods used and which he had elaborated, a great deal of the credit was due to Mr. Fewster for the detailed design of the mechanical features of the balance and to Mr. Lavender for many suggestions and criticisms.

Replying to Professor Hill, he said that the indefiniteness of maximum lift did not appear to be necessarily associated with high values. It was not a question of sacrificing high lift to obtain steady values, but rather of using the tunnel to show which sections were unsteady and avoiding the use of such sections in practice. The unsteadiness, he thought, was intimately bound up with the curvature near the leading edge of the wing. With regard to the Parasol drag results, he admitted that the differences were surprising, but could see no reason why the tunnel results should not apply to the full scale if the machine were similar to the model. The experiments in hand on an exact model of the Parasol wing with its excrescences would settle the point in due course. The low profile drag of the R.A.F. 48 section was also surprising, and thicker sections should be tested later on to see how far the thickness could be increased before a substantial increase of profile drag resulted.

Replying to Mr. Manning, he said that the American sphere turbulence tests in free air had been made in good and bad weather and also flying as close as possible to the ground. In the last case an increase of turbulence was indicated, but it was exceedingly small. The points raised on polished surfaces and on excrescences small compared with the boundary layer thickness were covered in the reply to Mr. Green. As regards the peculiar behaviour of T. 64 section it might be interesting to test this wing in the C.A.T. at some time.

Dr. Roxbee Cox was surprised that the correction for deflection of the aerofoils under load should be a constant angle change along the span. The lecturer had not tried to work this out for the elastic properties of the section and the position of the points of support. It was an experimental fact, and greatly simplified the application of the corrections. On the question of airship drag he pointed out that even in the C.A.T. the Reynolds number of an airship was unapproachable, but he hoped to test some airship shapes up to the maximum value available. The agreement of old wind tunnel results with full-scale deceleration drags he could only explain as a happy coincidence, but, as he illustrated by a diagram on the board, it appeared that the tunnel results were at such a Reynolds number that they lay on a transition curve which was nearly horizontal at the highest Reynolds number attained and had at this point an ordinate very nearly the same as that of the turbulent skin friction curve at the Reynolds number of the full-scale airship.

Replying to Mr. Winny, he said that as stated in the paper, he was unable at the present moment to explain the results on cylinders of different diameter. He could only suggest that eddies of the size present in the air stream seemed to affect the boundary layer more readily on the small cylinder than on the larger ones. He agreed that it appeared as though the maximum lift of aerofoils was not much affected by a small degree of turbulence. Sphere drag was affected considerably, and it was this which led him to make the statement that the critical

behaviour of spheres was not necessarily a guide to the effect of turbulence on other critical phenomena. He thought there was definite evidence that certain very thin sections did not give maximum lift coefficients approaching 0.7, *e.g.*, there was V.D.T. and full-scale evidence that R.A.F. 15 did not give much over 0.55. Possibly tests on thinner sections than those dealt with in the lecture would be desirable to establish this point more definitely.

He was extremely interested to see the written communication from Dr. Max Munk, who had had so much to do with the Variable Density Tunnel, and whose comments were therefore of particular value. The first suggestion of a Compressed Air Tunnel has usually been attributed to M. Margoulis, and it was exceedingly interesting to know that the original suggestion had come from Dr. Munk. He was entirely in agreement with Dr. Munk that the tunnel should be used as much as possible to advance our general knowledge of aerodynamics, and not merely as a " slot machine " for testing designs. It was, however, undeniable that one of the main objects in view in providing this very costly tunnel was that it should give aerodynamic data which would enable the designer to calculate the performance of his aeroplanes with much greater certainty than he could from ordinary tunnel results; in other words, to eliminate the uncertainty arising from scale effect. It was therefore of the utmost practical importance to be certain that this end had been achieved, and it was for this reason that the comparisons with full scale were being so carefully conducted. There was no intention of using the tunnel purely as a testing machine, though a considerable amount of pure test work would certainly be done in it on account of the more direct application to full scale. It was, in fact, anticipated that an increasing amount of time would be devoted to pure aerodynamic research in the tunnel as soon as some of the more pressing problems of scale effect confronting the designer had been solved. In this connection, it was disappointing to find that after some twelve years of working the Variable Density Tunnel appeared to have been used for little else than testing wing sections.

The PRESIDENT: In proposing a cordial vote of thanks to Mr. Relf, he said he had not thought it would be possible himself to contribute a word of useful knowledge upon this very advanced subject, but Mr. Wimperis had introduced the subject of golf balls and that gave him an opportunity to speak. It was interesting to drive a golf ball with various form effects and marking. The manufacturers of golf balls gave a good deal of consideration to that because the amount a ball soared depended on the back spin imparted to the ball and the amount and depth of indentation on the ball. It would be a distinct advantage if we could get a ball which would rise, due to back cut, and not turn to the right or left due to slice or pull! In congratulating the author on his lecture, the President said that not only had this difficult subject been put forward in a most effective and interesting manner, but it could be seen from the instruments that had been devised how much extraordinary human ingenuity had been put into this work.

The vote of thanks was carried enthusiastically and the meeting closed.

AIRCRAFT PRODUCTION METHODS

BY

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Lecture read before the Yeovil Branch, November 15th, 1934.

The object of production is to give service to the user. The value of that service is generally measured by the results obtained (either by way of performance, ease of maintenance, reliability, long life, and appearance) against the cost; and given two similar products, by which I mean products designed to fulfil identical functions, the purchaser will prefer the one which gives him equivalent or greater service at the lesser cost.

Some of the major factors entering into cost are:—

Building charges.
Plant charges.
Design charges.
Labour charges, both direct and indirect (including inspectors, store attendants, labourers, foremen and internal transport).
Administration charges.

Building Charges

Except when an entirely new factory is being planned for a preconceived product, building charges must, in general, be accepted as fixed and unvarying.

Most of the aircraft factories in this country were war productions, planned to suit the exigencies of the moment, and the different methods and materials then in use, and in many cases the layout and relative location of the building, renders it impossible to employ the floor area at the greatest efficiency.

Plant Charges

It is admitted that almost anything can be produced more cheaply than at present, providing sufficient time and money can be given to the design and production of special plant; but the present and potential sales of the aircraft industry in general seldom or never justifies batch order of more than 200 aircraft, and plant and tools must be budgeted for accordingly.

It follows that the aircraft constructor can have but few expensive single-purpose machines, and that, to give an adequate return on capital expenditure, the production of such machines must be utilised by the designers to the fullest possible extent.

Temporary Tool Charges

To a certain extent the same remarks apply to tool charges—although the governing factor is here the size of the batch for which the tools are required, *i.e.*, if the amount allocated for tool expenditure on a particular batch is £5,000 and the number of special templates, press tools, drilling jigs, rolls, jig frames, etc., is 500, the average expenditure is limited to £10 each—if this number of

special jigs, etc., can be reduced to 100 (*i.e.*, £50 each), the possibilities of cost reduction are much greater.

Labour Charges

The labour cost is governed chiefly by quantity—the simplicity or complexity of any part is a secondary factor if the quantities are sufficiently high and (equally important) if the part can be sufficiently standardised to permit employment in future products; in such a case tooling can be elaborate and costly, with every expectation of an adequate return. Unfortunately orders for aircraft are not large, and equally unfortunately designers seem to find great difficulty in achieving even a minor degree of standardisation in the details of their products. We are thus driven to the employment of more or less skilled hand labour, which is expensive. Not expensive in hourly wages—which is a poor criterion—but in hourly output.

Inspection Charges

Here, again, inspection charges are governed largely by the quantity of each item produced. The more intensively details can be tooled, the more the inspector can rely on selective rather than individual inspection—by which I mean that centre lathe parts, relying on the skill of the operator, must be individually checked, whereas if the number of the same parts is such that they can be economically made on a capstan or automatic, visual inspection of all, with a percentage of dimensional check, is quite effective.

Administration

Apart from such " necessary evils " as works managers, foremen, draughtsmen, and even directors, shown as " unproductive " in the salary lists, the size and cost of two departments in particular is very largely governed by the variety of the detail products. I refer to the stores and purchase sections. The larger the variety of materials and sizes which have to be carried in stock, the greater the floor space, storage and handling requirements, and, with the close control which has to be exercised over all aircraft materials, the larger the clerical staff required to deal with stores matters. The same argument applies to the production and progress office—if one batch of 100 parts can do the work of two batches of 50 parts, the cost of ordering on the shops is halved.

Design

I have already said enough to indicate my belief that plant charges, tool costs, labour charges, inspection charges, and certain administration charges, are very largely governed by the designer, who, in turn, is to some extent governed by his directors' manufacture and sales policy. The designer's creations are successful—as we measure commercial success—if they meet two requirements: Firstly, if they give a performance equal to or better than the specification demands, and secondly, if orders can be obtained sufficient in extent to recover the experimental and research charges, and give sufficient profit after meeting standing charges to give a return on capital invested plus a contribution to further research work.

The design must, therefore, be suitable for economic construction, bearing in mind the limitations of plant and tools which small batch production imposes and to which I have already referred.

The works manager has three " tools " with which to obtain economic output—plant and machinery, labour, and methods.

Plant is governed by the considerations already specified.

Labour—even given maximum co-operation—has its physical and mental limits; and it must be recognised that not more than one in every ten craftsmen really merits the term; therefore one cannot count on having a supply of highly-

skilled workmen to carry out all work. The production manager has therefore to exercise his ingenuity on devising better and cheaper methods of using plant and labour.

I propose to give a number of examples of the methods employed both in our works and others.

Taking wings as the first unit, we have, broadly speaking, two types. We have in general use in this country the two- or three-spar type joined by drag struts and braced by means of struts or wires to form a girder, covered with either linen fabric or sheet metal, or a combination of both.

The best form of spar from the production viewpoint is a tube of circular section—unfortunately an uneconomical spar as regards strength/weight ratio. The labour involved in the spar shown in Fig. 1 is confined to cutting off the tube and drilling holes for the end attachment fittings.

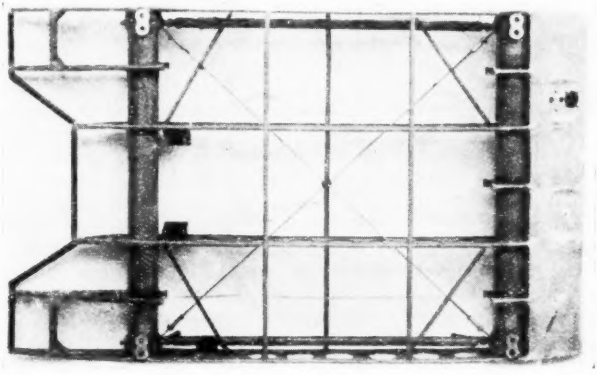

FIG. 1.

A development of the use of tubes is the Fairey spar (see Fig. 2*a*), which is a steel tube drawn to special section. Here the labour cost of converting the tube into a finished spar is small, being limited to the insertion of round tube—to reinforce the spar locally—and drilling the necessary holes to take strut and wire attachment fittings.

An obvious development of this spar is the Hawker Armstrong or Boulton and Paul type, in which top and bottom booms of tubular form are riveted to a flat or corrugated web (see Fig. 2*b*). Whereas, in the spars previously shown, the aircraft manufacturer's work is confined to cutting to length and drilling, with this last type he has very considerable work to do to produce his spars from the bought out materials.

A spar of this type necessitates—to procure each individual section—two sets of rolls, averaging about five pairs of rolls per section. For the section shown, the cost of the blank rolls (including machining) cannot be less than £8 per pair. Despite much accumulated experience in the design of rolls and dies for such sections, and the development of empirical formulæ, the production of such rolls to accurately-formed, predetermined profiles is still to a certain extent a matter of "cut and try." I have known a week to be spent in modifying one pair of rolls to correct a section which was only 1/16in. out. Mr. Langley, in his book on "Metal Aircraft Construction," says: "For economic reasons the designer should not demand extreme accuracy in the works, unless production is on a large scale. One might suggest that the alteration of figures and drawings is cheaper than the alteration of dies and rolls. This suggestion is not made to give the works unlimited licence, but merely to acknowledge the difficulty of

Fairey Type Spar (Steel). Fig. 2a.

Hawker Type Spar (H.T. Steel Strip). Fig. 2b.

Steel Wing Co.'s H.T. Steel Box Spar. Fig. 2c.

Typical Continental Spar (Dural). Fig. 2d.

Typical French Box Spar (Dural). Fig. 2e.

shaping a die to produce a given section, making allowances for ' spring back ' in the drawn metal."

Having drawn the sections, the next operation is to assemble the booms and web together. Some firms' method is to fit the spars on to a jig and punch one hole at a time—a rather tedious method.

Our own method, which is somewhat better, is to gang-punch all holes in boom strips and assemble to the webs in a jig in order that all holes may be drilled through the pre-punched tools—tack rivets are inserted by hand and the assembly then removed and taken to the riveting machine.

The best method of riveting such a spar is that employed by certain British firms in the production of Hart spars—unfortunately not applicable to most spars of rectangular section. The sections are threaded into a series of rollers which maintain them in true relationship and feed them between top and bottom blocks—the lower carrying punches which punch the rivet holes, followed by jaws containing snaps and dollies which close the rivets.

A machine of this type would cost £250, apart from the development cost, and is of course applicable to one type of spar only.

A comparison of the two types of spar (Figs. 2*b* and 2*c*), which I call the single- and double-web types respectively, shows—from the production viewpoint—that the single-web spar has several advantages over the double-web.

(*a*) The number of sections used is the same in both cases.

(*b*) The weight is slightly in favour of the single web.

(*c*) The single-web type, as illustrated, has two rows of rivets only. The double-web type has four rows of rivetings. As, however, the pitch of the rivets is, in general, closer on the single-web type, the saving would appear primarily to be one of setting-up only. Other factors, however, have to be considered: Firstly, the cost of drilling or punching holes, which must be at least double in the case of the two-web spar (two traverses, etc.) ; secondly, the ease with which each individual rivet can be inserted in the single-web type by a single in-and-out motion is obvious. Whereas, with the double-web type, the rivet usually has to pursue a right-angled path during insertion.

To produce a 20ft. spar of the corrugated box type we have to:—

(1) Set up two sets of rolls (*i.e.*, 10 pairs) to roll the webs and booms.

(2) Punch a total of 480 holes in the booms. This necessitated a travelling jig 22ft. long, with the holes accurately set out and a gauged punch and die punching holes on each edge simultaneously.

(3) Punch four groups of holes in each of the two webs—totalling 72 holes. Each group is made by a gauge punch and die punching nine holes simultaneously—the punches must have a maximum clearance of .002in. in the dies, and with these small punches the average life before breakage is about 600 holes.

(4) Produce six different pressings for riveting to the webs to take lift fittings, etc.

(5) Rivet the pressings to the webs.

(6) Assemble the webs by means of distance sleeves.

(7) Fit internal diaphragms at every 2ft. clamp, with the booms in a jig, and drill through.

(8) Insert all rivets and close in a pneumatic riveting machine.

(9) Fit an end casting and rivet on.

The length of this spar is just over 20ft.

The weight of this spar is just over 22lbs.

The total number of different parts in this spar is 39 (excluding rivets).

The total number of rivets in this spar is 844.

The total number of special tools or tool groups involved is 23, apart from riveting tools and jigs, and for high production and maximum economy this number of tools should be at least doubled.

The originators of this type of wing had built several hundred sets of wings before we undertook the manufacture, and after the initial difficulties had been overcome, this spar was not particularly difficult to manufacture.

In planning the job, however, and knowing that tool expenditure must be budgeted for on a shrinking output, we naturally looked for opportunities of simplification. To take one point, we found that the rivet positioning differed on top and bottom front and rear spars, necessitating four spacing bars for the punching jigs. A little investigation showed that by adding a few rivets at certain points and eliminating others, all front spars top and bottom could be identical as regards rivet positioning—similarly all rear spars. The drawings were altered to meet this point, and two spacing bars were eliminated, in addition to eliminating the risk of getting the wrong webs in a spar.

We also found that in the top rear spar the design called for a different material for the booms (D.T.D. 99), whereas on the lower rear spar and all front spars D.T.D. 100 (a slightly stronger material) was used. As this difference meant a duplication of purchase orders, increased inspection, and again the risk of getting the wrong material into a spar, we investigated this point and found that the better material could be used throughout. The cost was the same, and we eliminated certain tools and the possibilities of certain mistakes—both tools and mistakes are expensive.

This particular spar has one merit from the production viewpoint. The same booms and webs are used for front and rear spars, in fact the overall section of all spars is the same. Undoubtedly the designer has sacrificed a little here in not attempting to obtain the maximum mean height available in the wing profile, but as the weight of these wings in lbs. per sq. ft. is quite reasonable, he would appear to have given away very little, whilst obtaining considerable production advantages.

With the exception of, I believe, Breguet in France, none of the Continental firms appear to use the strip steel construction favoured in England. Examination of French designs makes one consider their strip steel spars clumsy in design compared with British spars of similar size, without having the merit of simplicity.

French duralumin wing spars are, in general, fairly simple and would appear to be designed with an eye to ease of production. (See Figs. 2*d* and 2*e*.)

They are, in most cases, of " I " section using a plain sheet web, sometimes unlightened, sometimes lightened by triangular holes giving the form of a lattice girder. The flanges are formed by riveting on plain extruded angle, sometimes tapered in width and depth, but constant in thickness. The rivets are extremely accessible, and like the Hawker spar, capable of continuous machine riveting.

A spar such as this is obviously a very good production proposition.

Box spar practice is much the same, except that the booms are not so simple, being formed either from a single central channel with two angles or from a special channel section.

Here, again, in some cases the lower channel is inverted to enable rivets to be introduced easily; admittedly an uneconomical disposition of material, but considered worth while by the designers.

It is difficult to get any knowledge of the German practice, but, apart from the latest Heinkel, the Junkers is still the pre-eminent civil machine, and is very interesting to the production engineer.

Since the commencement of deep wing construction, Junker has used tubes for the booms of his spars, which are an extremely simple production job, in spite of their size.

The inner end of the spar has webs of corrugated sheet, with rivets driven in from the outside; the outer end of the spar has lattice bracing riveted on in the same way. (See Fig. 3.) The bracings are of " Zeppelin " section, drawn in long length, sheared off and flattened at the ends. The diameter of the tubes is reduced towards the tips, either by telescoping one within the other or by a

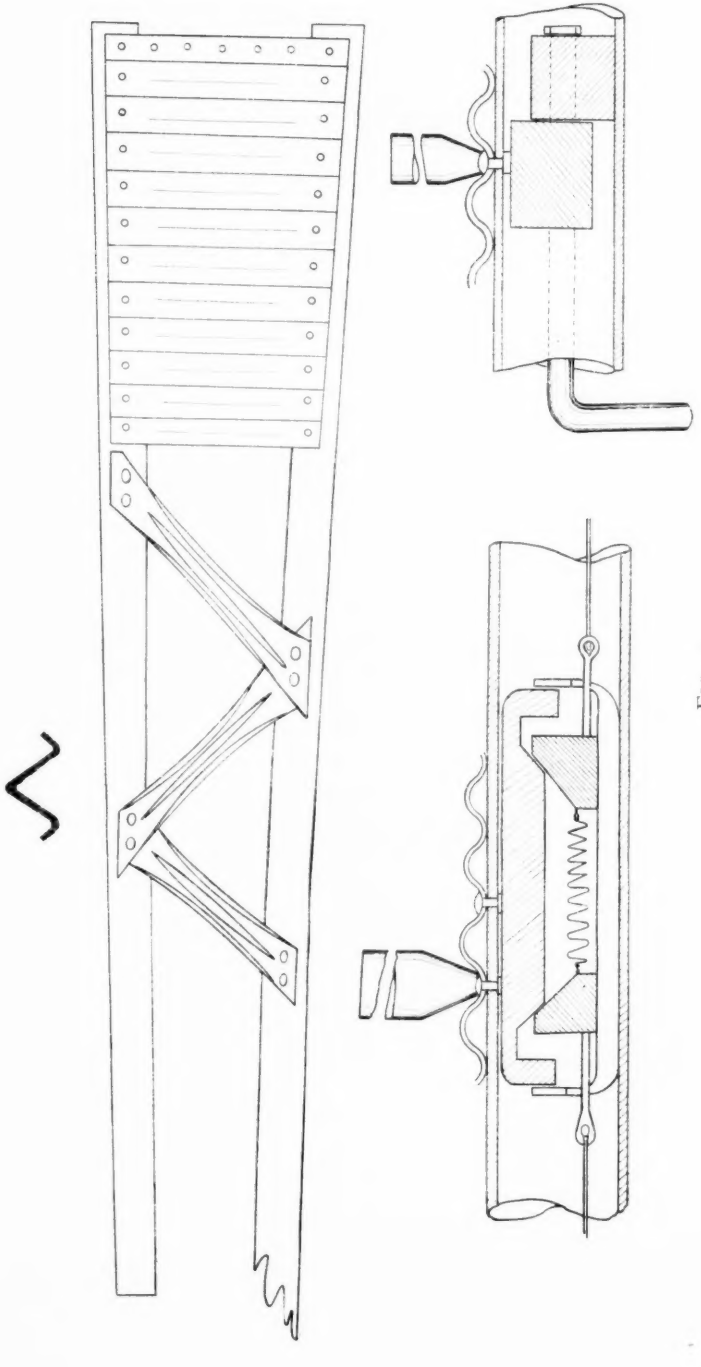

FIG. 3.
Junker Spar Construction.

single internal sleeve, riveting again being done from the outside. To reduce a large tube to telescope over a smaller the end is squared, with corner radii of such dimensions as to use up the "periphery."

If this is compared with British machines of similar size, the comparative simplicity of the Junker method is obvious.

So much for the comparison of spars. Ribs, though diverse in detail, fall into two categories at once. Solid and built-up. By solid I refer to the pressed type, which—in production—will, I think, prove to be most economical in labour cost. For large ribs very considerable ingenuity would be necessary for the designer to obtain a light pressed rib without having recourse to too many lightening holes and consequent waste of material. (See Fig. 4, *a* and *b*.)

The built-up rib can be either comparatively cheap or extremely expensive. The Wallace standard rib is of the first type, two sections only being used, top and bottom channel booms rolled to section and a lattice bracing section, the bracings are flattened locally and bent to lattice shape. In the construction of

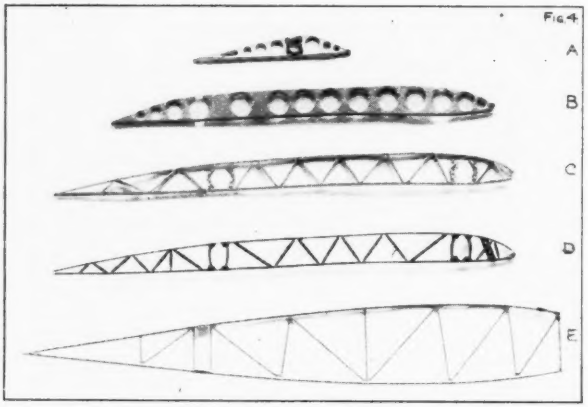

Fig. 4.

these ribs the booms and bracings are jig drilled before assembly; and it is possible to assemble without special assembly jigs, maintaining an accuracy of less than 1/16in. overall within profile limits; the work can be done entirely by boys; in addition, the holes can be punched, which is much cheaper than drilling.

It is interesting to make a comparison of three ribs of more or less identical profile. The built-up duralumin rib Fig. 4*c* is made up of a total of 144 parts, of which 92 are rivets and distance pieces, leaving 52 parts which include channels, angle bracings, attachment plates, etc. The weight is low—11½ozs.—but to get this low weight we are utilising 144 parts.

The steel wing of identical profile Fig. 4*d* weighs 25 per cent. more and has a total of 64 parts, of which 45 are rivets, *i.e.*, apart from rivets this rib has 19 parts only, compared to the 52 of the duralumin rib.

The third rib is pressed from one piece of metal only, and weighs 12½ozs., and I have estimated that the weight would be increased to 13½ozs. if allowance was made for the two attachment flanges and eight rivets. It will thus be seen that we have an extremely light rib (11½ozs.) made of 144 parts, an intermediate duralumin pressed rib of 13 ozs., which, with its attachment flanges and rivets would incorporate 11 parts only, and a steel rib, of admittedly somewhat obsolete design, which incorporates 64 parts and weighs 14½ozs.

Since the pressed sheet duralumin rib is obviously heavy and could have been lightened to a greater extent had we gone to the expense of making special press tools, I feel that these three examples show that the pressed rib on small machines must not be neglected. There is, admittedly, a certain waste of material, but the savings in other directions are so obvious that I feel this example shows that simplicity does pay.

The built-up tubular rib (Fig. 4*e*) is usually more expensive than the type first described, owing to the cost of small light gauge tubes and the number of clips and rivets required to hold it together. The number of rivets is doubled or trebled, and the number of tools is increased by several hundreds per cent.

Probably the cheapest form of rib (in smaller sizes) is the welded steel tube type, as used by Fokker for all fabric-covered components, and now being used in England. The material is certainly rather heavy, but the homogeneous joints and consequent stiffness obtained by welding certainly permit a reduction in the size of the tube sections used. For intensive production this method would not be suitable, as too many jigs, each requiring a fairly skilled welder, would be required, but for a batch of, say, 20 to 50 machines at a time, I suggest there is no better method. For experimental work it is definitely the cheapest method.

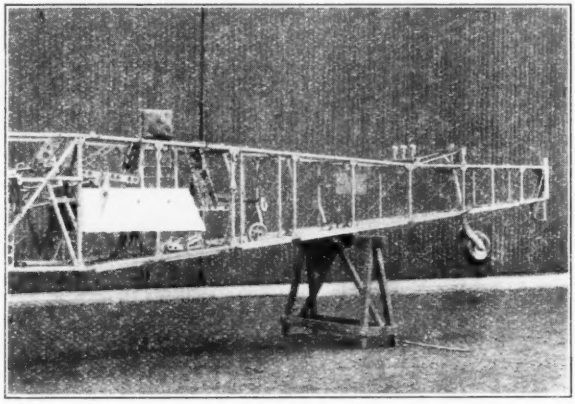

FIG. 5.

Fuselages

In production there is no doubt that, up to a certain size, the riveted tubular type is the cheapest and lightest. (See Fig. 5.)

It can be very fully jigged, with all holes predrilled, enabling the use of labour not highly skilled for assembling. The joints can be single plates, and sub-assemblies are easily arranged to facilitate final assembly. Work need only occupy the jigs for the time it takes to insert rivets, as riveting can be completed off the jig. Replacement and repair are easy, and inspection is a comparatively simple matter.

If, however, the designer allows his imagination to run riot, the number of single flat plates may increase to such an extent that, for small batch production, press tools and jigs present a serious problem to the production engineer.

A good blanking tool will cost from £5 to £10 to produce, even for a small blanking. The same tool to blank and punch will cost about double. A batch of, say, 50 machines necessitating 100 blanking tools might therefore require about £700 expenditure on small press tools alone—only £14 per machine, it is true, but alternatively, this amount will pay 42 18-years-old apprentices for

16 weeks, and this number of lads would file up the blanks in less than half that time.

To return to fuselages—the welded type has a great advantage, inasmuch as detailed jointing parts are largely eliminated, with a great saving in design and tooling cost; attachments are made easily and cheaply; and, again, for experimental work the system has the great advantage that alterations are easily made.

The monocoque or shell type of fuselage is practically unknown in this country. It is certainly heavier than the framed and fabric-covered fuselage of similar size; and is, with equal certainty, more easily maintained; and is probably stronger owing to the redundancy of structure.

Quite frankly, I have no idea of relative costs, but it is known that the Douglas twin-engined machine costs about £30,000—or over £2,000 per passenger per 1,000 miles. Labour costs are of course high in the U.S.A., and as a great proportion of the work must be carried out by skilled labour, it is probable that the cost would be lower in this country. Against this it is understood that the Blackburn B.2 Trainer, which is a two-seater of medium performance with open metal monocoque fuselage, seating two people side by side, costs about as much as a Puss Moth with similar engine, but with the refinement of air brakes, wheel brakes, enclosed cockpits, etc.

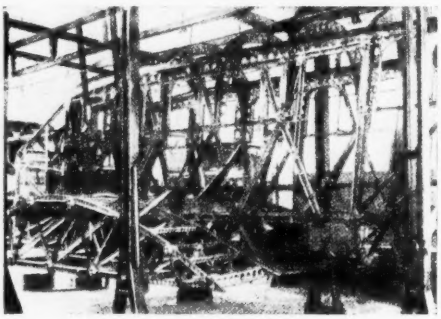

FIG. 6.

For machines of above 6,000lbs. in weight, I personally believe that the monocoque system could be made as cheap a production job as the framed and fabric-covered fuselage—the additional weight of the primary structure being offset by the saving in fairing, covering and saving in internal equipment costs.

Some years ago I was privileged to see the construction of the Junkers all-metal fuselages.

The first stage is the manufacture of the inner bulkheads—invariably channel frames rolled to shape and reinforced by corrugated or plain sheet riveted on. (See Fig. 6.)

I do not know the American practice, but the German methods at Dorniers, Junkers, and Rohrbach, do not call for extreme detail accuracy except in isolated cases. The large size of all plates, etc., makes it possible for tolerances to be wide, and interchangeability of panels, bulkheads, etc., is not aimed at. In fact at one German works I saw joint plates being marked off by the simple process of punching through the black and white prints, shearing to shape on guillotine, and drilling straight from the punch marks.

Jigging is only done to ensure interchangeability between components of, say, the junction between the wing and fuselage, and drawings are issued at a

very early stage in order that jigs may be made before the construction of either of these components is commenced.

These methods are eminently those of common-sense when one realises that most repairs can be carried out with equipment consisting only of shears, drilling equipment and riveting snaps, providing a stock of the necessary plates is kept.

So much for components in general; now a few words about detail parts.

Naturally, having to produce them and being held responsible for the final cost, we think there are too many and we feel that a little ingenuity on the part of the designer would help in this respect. Fig. 7 shows a junction point using three plate fittings (actually there are two of each). I will agree that all these plates are simple to produce, and are not in themselves expensive parts, but I

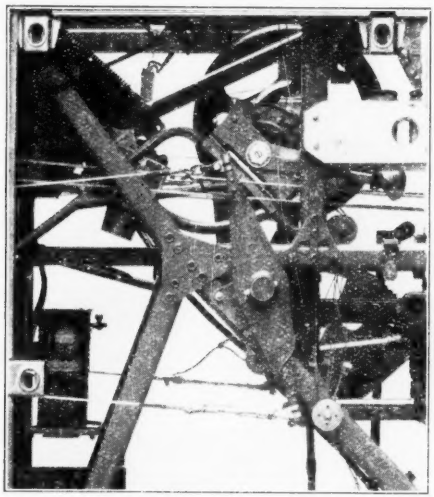

FIG. 7.

submit that one joint plate incorporating the bearing could be designed, and only one-third the number of press tools and drilling jigs would then be required. The inspection processes, with their accompanying advice notes and other records, would be cheaper, and, since it is cheaper to locate one fitting than to locate three, assembly charges would be reduced. (N.B.—This example was on an experimental aircraft which never went into production.)

Fig. 8 shows how a very simple design alteration made a simple press tool job of three hand-made plates, and actually saved weight. A very simple example, but the saving is obvious.

Generally speaking, I think I can say that we have no objection to complicated parts, providing we get enough of the same sort to pay for tooling and production investigation. One off per machine does not give us much opportunity for reducing production costs. The designer will reply: "Oh, yes! But if you can get an order for 100 aircraft you can make 100." The answer is that we seldom get an order for 100, and secondly that when we do, we generally have to split these into batches of, say, 25, in order to get away quickly with the job.

As regards machining, again we do not mind complex work, if there is enough of the same sort, but we feel that the design frequently makes us expend

a lot of power and labour and valuable machine hours in removing valuable metal as waste.

This particular part (Fig. 9) weighs 24½ozs., the billet from which it was machined weighed 128ozs., the cost of the metal removed being 4s. 0d. The obvious answer is to use stampings, but the stamping dies would cost at least £8, so that it would be necessary to produce at least fifty parts to compensate for the cost of the dies, and machining stampings which have to be chucked is not so easy as machining from the bar. Personally, I would have designed the flange to screw or key on to the shaft, particularly as the shaft is already splined for another purpose. In this particular case the parts cannot be welded, but I believe that a great deal of machining (perhaps I should say roughing out) will in the future be eliminated by the use of welding, probably arc welding, which has not been applied to aircraft construction in this country, but is largely used in other industries and is being used in the United States on aircraft work by the Boeing Company. I feel that some of the machined from solid parts which

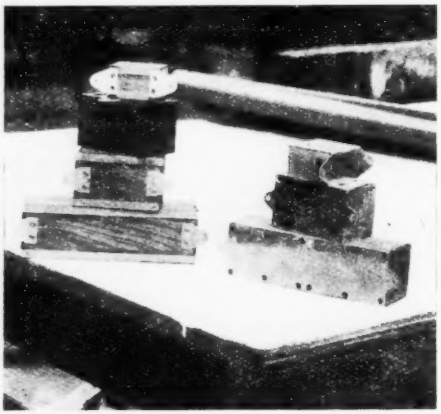

FIG. 8.

present technique forces the designer to employ will in the near future be arc welded and subsequently machined only at essential points. This cannot, of course, be done with light alloys, but it appears that the practice of Junkers, Dornier and Rohrbach, in Germany, of using light alloy structures having steel junctions for points of concentrated loading is being followed in America, no doubt for sound reasons, and I doubt whether steel will ever be replaced by light alloys at such points.

I have recently been told that welding is an obsession with me. If so I am in very good company.

This is the statement of a very eminent production engineer: "In every case when welding has been adopted it has made possible a decrease of weight without decreasing strength, and a decreased cost of manufacture without lessening quality.

"The ability to combine parts by welding means the introduction of a whole new technique into metal manufacturing and we have only just started." The writer was Henry Ford, who has forgotten more about production engineering than most of us will ever know.

I will admit that we have still a lot to learn about welding, and that failures of welded parts, although very rare, still occur—though I think the percentage

is no higher than for cast, stamped, or riveted parts. But it must be remembered that casting, forging and riveting are processes hundreds of years old, and, to use an Americanism, " have the bugs ironed out of them," whereas welding is a young process and we are still learning.

Also I feel that designers generally look on welding as a job to be handed to the shops to get on with, and that they are not sufficiently interested in this new tool to follow up its developments outside their own particular field of operations. In short, they lack faith.

If any of you want to see the faith we have in welding look at the gear on which we sling our engines in the shops. We hang them on welding.

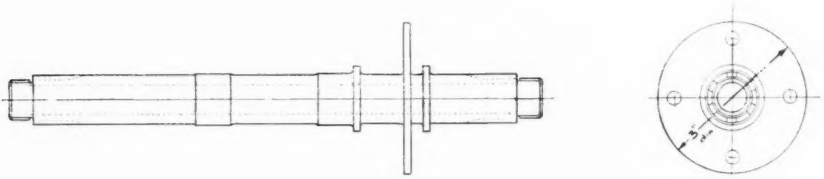

FIG. 9.

Design Technique

We do not know yet what materials can or cannot be welded—we know that some weld easily and that some are very difficult and at present impossible. I feel that we want more research work—not by the metallurgist or the producer of sheets and tubes, but in workshop methods of manipulating and joining these new materials.

This brings me to another point. Just as most aircraft firms spend large sums annually on wind tunnel and general aerodynamic research, I suggest that money should be spent on what one might call manufacturing research. At the present time much work of this kind is carried out during the construction of experimental craft—with consequent delays in their production—and worse still, it is carried out by foremen who are already fully occupied in the endeavour to get out production work and who have not the time to supervise and control experiments in manufacturing processes.

It is quite candidly not fair to the workman, the foremen, or the material to produce, say, a new type of tank construction using, in addition, a new metal, and to damn either the material or the workman if the first or even the second attempt is not successful.

Simplification

It will be seen that throughout this paper I have pleaded for greater simplicity. After all the cleverest designer is the man who obtains the maximum result at the minimum cost.

Simplicity, and under this heading I include the reduction in the number of detail parts, affects every branch of the production system. The Purchase Dept. has fewer orders to contend with and follow up; the Stores have fewer materials to budget for and keep in stock; and the Production Office, which issues work, requires a smaller staff. The present Air Ministry system, which requires us to keep a check and have a record of the material used in every single part in our assemblies, necessitates that every part or batch of similar parts going into the shops must be recorded in such a way that we can trace the material several years afterwards.

An order for one plate going into the shops is accompanied by the drawing and material requisition, and a job ticket for each operation. If 100 parts of

the same kind are sent into the shops we still require only one drawing, one requisition, and one job ticket. If instead of these 100 parts we have 25 different parts, and used four only of each, then we have 25 drawings, 25 job tickets and 25 stores requisitions.

Similarly, the foreman when passing his completed work into the view-room has his clerical work increased 25 times; the inspector, instead of using one gauge, template or jig, uses 25 gauges; and finally a problem which is becoming very pressing, the storage requirements for these parts are multiplied 25 times.

I am fully aware that I am suggesting perhaps a measure of standardisation which is very difficult of achievement, but after all standardisation essentially means finding the best possible way to do a job and sticking to it until you find a different way which is so much better that it is worth changing over to.

Labour

There is one other factor which, in the event of war, might have a very serious influence on the output of assembly. I refer to the labour question. Even during the War of 1914-1918, when aircraft construction was comparatively crude, a great deal of difficulty was experienced in obtaining sufficient labour, and this applied to not only aircraft but to all munitions. The labour available was petted and sacrifices were made both by the Government and the engineering employers generally, which increased labour costs not only during but after the War to a considerable extent.

Our machines are now becoming so complex, particularly with regard to the number of parts which go into their construction that even in peace time it takes a long time to tool-up machines to the stage of really high production.

Furthermore, the skilled labour required to get quickly into high production very definitely does not exist. We have, I believe, as good craftsmen now as we have ever had, but there are not enough of them for modern requirements. This condition may possibly be corrected within the next ten years by more intensive and better training of apprentices, but it is definitely a position which must be considered by the designer for several years.

The number of sheet metal workers, for instance, who can make tanks of the type now required for evaporatively-cooled engines is very few, probably not one in 100 if we took the sheet metal industry of this country; and the number of machinists who can set up other than simple work without the assistance of a setter-up or of gauges is probably in the same proportion.

I do not think I am giving away any secrets when I say that this shortage of skilled men is a matter that is at the present time engaging the very serious attention of those who direct the engineering industry of this country, and conversations I have recently had with other executives in the engineering industry convinces me that the problem is a very real one.

I do not wish you to think that we cannot tackle what you give us to make; as most of you here are aware, practically the whole of the Wapiti metal fuselages were built by men who had previously been employed on the construction of wooden fuselages; but the transition period when we were trying to get production and at the same time to train these men was a trying one, and we do ask the designers not to add to our difficulties.

Discussion

Captain Keep: He commended the plea put forward by the lecturer for standardisation for similar detailed component parts, and also recommended as far as possible the design of sub-assemblies such as controls in unit form so that they are easier to produce and assemble on the bench, and finally erect into the machine as units.

Mr. DIGBY: Referring to the lecturer's remarks on welded construction, he suggested that this construction had been neglected in the past because of the lack of suitable high grade materials capable of being welded.

Mr. GIBSON: He did not think this was the case, as even so long ago as 1913 at Graham White's he had made elevators in 35 tons steel tube of welded construction.

Mr. PITCHER: He inquired as to whether the welded type of fuselage was not more difficult to repair as facilities will not exist in out of the way places.

Mr. GIBSON: There were very few localities where there was not a welding plant within easy reach and even if one could not immediately effect a welded repair there were schemes available for sleeving and riveting, or bolting temporary patch plates, which would serve until the machine could be flown to a suitable depot for the affected members to be cut out and new ones welded on.

Mr. WIDGERY: Would the necessary skilled labour be obtainable to effect a welded repair in many places?

Mr. GIBSON: The method to adopt where such skilled labour was not available was to make a temporary repair by sleeving and bolting until the machine could be flown to a suitable depot.

Mr. RICHARDS: In the case of damage to a welded structure, was there not likely to be a good deal of consequential damage in other parts near by, that is, the damage was not so localised as with other methods.

Mr. GIBSON: Fokker had used the welded construction for many many years and his machines had been in service to many parts of the world, and he thought that the practical experience obtained from that showed that the scheme was quite suitable for maintenance and repair, and that one or two English manufacturers had supported this belief by copying his methods.

Mr. RICHARDS: Would not the Monocoque type of fuselage be very costly?

Mr. GIBSON: He had no experience or figures relating to this, but from what he understood of the American Douglas air liner, the number of sections was kept to the minimum, only two or three sizes being used for skin stiffeners throughout the fuselage, and the sheet was all in standard 2ft. wide panels, and only varied very slightly in thickness from 20 gauge to 16 gauge, the majority being about 20 gauge, and therefore he thought that in quantities for large machines the Monocoque system of construction would be economical.

Mr. WIDGERY: Had the lecturer thought that arc welding would have any advantages for aircraft manufacture?

Mr. GIBSON: He did not think there was a particularly great future for this type of welding, although interesting developments of a limited application were possible, but if riveting was made accessible this method of fabrication was quite satisfactory.

Mr. DAVENPORT: He would like to express his appreciation of the lecture and said that he thought Mr. Gibson had stated the problems and given the answers to most of these problems himself. It was obviously very difficult to decide in advance whether the quantities of machines likely to be ordered would justify certain types of construction, and a satisfactory compromise was not always obtainable. In most cases it was realised that stampings would have to be used when the quantities justified them, and therefore the first machine might have to adopt manufacturing methods by machining from solid, which would appear to be expensive and uneconomical until the larger quantities came along. He expressed the opinion that it does not matter very much which type of construction is adopted so long as it is well designed.

Mr. GIBSON: There was a great difference between mass production and batch production and it was necessary in aircraft manufacture to design for

batch production as one hardly ever received orders which would justify what was known generally as mass production.

Mr. GAUNT (*communicated*): Does the lecturer agree that weight and cost could be saved by a reversion to wooden construction for such items as ribs, which would have the further advantage of employing another class of labour?

Reply: Yes, but only as an interim process—for mass production it must be metal.

A vote of thanks was proposed by Mr. DIGBY and carried with acclamation.

ABSTRACTS OF PATENT SPECIFICATIONS

(*Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.*)

Regular abstracts of Patent Specifications received by the Society are published in the Journal. It should be noted that these abstracts are specially compiled by Mr. W. O. Manning, F.R.Ae.S., for the Journal and are only of those actually received and subsequently bound in volume form for reference in the library. These volumes extend from the earliest aeronautical patents to date, and form a unique collection of the efforts which have been made to conquer the air.

The Council accept no responsibility whatever for the accuracy of the abstracts and in any case of doubt the full patent can be consulted when necessary in the library of the Society.

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Aeroplanes—Construction

418,256. *Improvements in and relating to Frame Structures for Vehicles, Marine Vessels and Aircraft.* Becker, W. A., 49a, Cicerostrasse, Berlin-Halensee, Germany, and Dr. H. Schlisinger, 7, Rue Saulnier, Paris, IXme, France. Convention date (Germany), Oct. 20th, 1932.

This arrangement is described with reference to motor car chassis. The proposal is to construct such chassis of metallic tube with corrugations encircling the tube so that the tubes are slightly resilient, the amount of resilience being controllable by the design so that the resilience presents permanent deformation. A drawing is shown of a car chassis constructed of two such tubes connected at one end by a U-member, and another showing a single tube of this line carrying the motor at one end and the back axle at the other.

417,212. *Improvements in or relating to Joists, Beams, Pillars, Struts, and the Like.* Symes, W., Irlesmore, Irlam Road, Flixton, Manchester. Dated, June 15th, 1933. No. 17,131.

This invention applies more particularly to girders, etc., formed from light alloys. In such girders of, say, H-section, it is usual to pierce the web with holes for lightening purposes. As this may have the effect of making the girder too weak to withstand the shear stresses imposed, it is proposed to strengthen the web with diagonally arranged ties fitted over the weakened portions of the web. These ties may be of material of greater tensile stress than that composing the girder.

417,178. *Improvements in Aeroplane Wing Structures.* Welman, F. S., 55, Pinnacle Hill North, Bexley Heath, Kent, and Lovell, A., 31, Chieveley Road, Bexley Heath, Kent. Dated March 1st, 1933. No. 6,175.

This describes a single spar wing in which, in addition to the spar, there are braced longitudinals running parallel with it. Ribs of normal type are fitted at intervals dividing the spar into bays and the bays are diagonally braced top and bottom by members capable of taking tension and compression loads. These members cross in the centre of each bay and run from the front to the rear longitudinally. Fabric covering strips are fitted over the structure. It is claimed that this method of construction is suitable for metal.

417,350. *Fuel Jettisoning Valve Arrangement for Aircraft.* The Blackburn Aeroplane and Motor Co., Ltd., and Rennie, J. O., both of Seaplane Base, Brough, Hull, Yorks. Dated, July 11th, 1933.

This specification describes a fuel tank jettisoning valve for aircraft in which the valve is of the mushroom type and can be opened and closed at the will of the pilot. The operating mechanism consists of two pistons in cylinders, the pistons of which carry racks which gear with a pinion. The pinion shaft carries a crank, the connecting rod of which operates the mushroom valve. Hence it follows that fluid pressure in one cylinder opens the valve while fluid pressure in the other cylinder closes it. The working fluid is oil under pneumatic pressure and the valves controlling the mechanism are worked by means of solenoids, controlled by the pilot by means of switches. Alternatively it is proposed to operate the mechanism of the oil pressure of the engine lubricating system.

418,776. *Improvements in or relating to Latch Gear for Folding Aircraft.* The Blackburn Aeroplane and Motor Co., Ltd., Seaplane Base, Brough, Yorks, and Petty, G. E., Pantiles, Brough, Yorks. Dated, Aug. 17th, 1933. No. 22,971.

It is proposed to operate hydraulically the locking gear for the folding wings of aircraft, so that there would be no difficulty in operating the gear in the upper wings of a biplane, though the scheme is equally applicable to monoplanes. The locking pins are operated by a hydraulic plunger and are controlled by springs which tend to keep the locking pin in the locked direction. The hydraulic pressure is applied by one or more pumps, fitted on the lower wing of the machine, and there is a safety device applied to the plungers which prevents movement of the pin until hydraulic pressure is applied. The pump or pumps may operate all of the pins together or each of them separately, according to the arrangement used.

419,099. *Improvements in or relating to Cellular Structures.* Senutovitch, W., 3, Rue Charles, Lamoureux, Paris, France, and Nobel, E. L., 4, Avenue Malakoff, Paris, France. Convention date (France), July 2nd, 1932.

This specification describes a method of making a multi-cellular structure in any metal or non-metallic substance which can be used as a structure for taking applied loads or as a heat or sound insulating medium. The foundation of the structure is a sheet of the material to be used. This sheet is bent into folds so that the end view of the sheet resembles a straight line with a number of cross arms, these cross arms consisting of the doubled material. The top and bottom of the structure may consist of a similar sheet bent so that in end view there are cross arms on one side only, and the folded edges of the first member are slotted so as to permit the folds of the second member interlocking with the folds of the first. By this means, and by the addition, if desired, of further similar members, a structure containing any desired number of rectangular cells may be built up. After assembling, the structure may be covered in any desired manner.

418,066. *Improvements in or connected with Biplane Wing Structures for Aircraft.* Vickers (Aviation), Ltd., and Wallis, B. N., both of Weybridge Works, Byfleet Road, Weybridge, Surrey. Dated, April 18th, 1933. No. 11,308.

This specification refers to biplane wings which are made self-resisting as regards torsion by the geodetic principle described in Spec. No. 36307/32 (Serial No. 412,232) and are provided with a single system of interplane bracing which may be arranged on the Warren girder principle. Hence the wing spars are relieved of much of the vertical load and it becomes possible to make them of uniform depth.

402,895. *Improvements in or Connected with Means for Launching Aircraft.* Mayo, R. H., 39, St. James Street, London, S.W.1. Dated August 19th, 1932. No. 23,286.

This specification relates to the scheme described in Application No. 12,013, 26th April, 1932, for the mounting of one aircraft on another so as to form a composite aircraft, the upper member of the combination being capable of being released in flight, while the combination or either component of it may be used, landed, etc., in the manner of an ordinary aeroplane. It is proposed to place the upper aircraft in a position slightly aft of the centre of gravity of the combination, so that when the lift of the upper component is increased, as previously described, for the purpose of getting off, the effect of this increased lift on the lower component is to reduce the lift of the latter, the purpose of the device being to facilitate separation of the two. A locking device is also described which is arranged to release the upper component when a predetermined excess lift acts on the wings of the upper component.

418,121. *Improvements in or relating to Aircraft.* Dr. Ing. C. Dornier, Friedrichshafen, Lake Constance, Germany.

This specification refers to a combination of rotatable blades with a fixed wing for aircraft, the object being to obtain the greatest possible difference between the flight speed and the landing speed, the fixed wing having an area sufficient only for high speed flight. It is proposed to mount the rotating blades towards the extremities of the fixed plane and to arrange that they can be retracted into the fixed plane in such a manner that a portion of one blade of each rotor extends beyond the fixed plane. The object aimed at is to reduce the area of the fixed plane, thereby saving weight.

400,292. *Improvements in Means for Launching Aircraft.* Mayo, H. M., 39, St. James Street, London, S.W.1. April 26th, 1932. No. 12,013.

This specification describes a method of launching aircraft by which the aircraft to be launched is mounted on or above another aircraft in such a way that it can be released when desired, thereby being in independent flight. It is claimed that there are many advantages to be attained by this method of launching, including the possibility of launching easily and safely aircraft with a high wing loading. Many methods are described for ensuring the safety of the releasing operation, including means for providing that the angle of incidence or the lift coefficient of the upper aircraft is increased to the extent necessary for continued vertical separation of the two aircraft. In order to attain the same end it is proposed also to throttle down the engines of the lower aircraft by automatic means at the moment of release or to provide air brakes. Matters connected with the control of the two aircraft are also provided for. There are many other precautions described to effect separation without affecting safety of operation.

402,951. *Improvements in or Connected with Means for Launching Aircraft.* Mayo, R. H., 39, St. James Street, London, S.W.1. Dated January 14th, 1933. No. 1,311.

This specification refers to composite aircraft of the type described in Specification No. 12,013/32 (Serial No. 400,292), whereby two aircraft, one on top of the other, are normally locked together to form a composite aircraft, and means are provided so that the upper aircraft can be released in flight. The arrangements described in this specification relate to wing arrangements devised to facilitate separation of the two components during flight. It is proposed to use, on the upper aircraft, a wing section possessing a larger angular range of lift than that used on the lower component, and to attach the aircraft to each other so that the wing of the lower component is at the angle of maximum lift while that of the upper component is unstalled. Suitable types of wing are referred to, and reference is made to the effect of slots and flaps on the operation of the device. It is shown that, by the means described, that at the minimum flying speed of the composite aircraft there may be a force tending to prevent separation of the components, while at higher flying speeds the force may be such as to produce separation. Methods are given for calculating an appropriate wing area for each component.

402,997. *Improvements in or Relating to Composite Aircraft.* Mayo, R. H., 39, St. James Street, London, S.W.1. Dated April 27th, 1933. No. 12,310.

This specification refers to composite aircraft consisting of two components mounted one on top of the other and provided with means by which the components can be separated in flight. The present specification refers to locking means which are arranged so as to prevent separation until the lift of the wings of the upper component reaches a predetermined limit sufficient to ensure safe separation. The locking means may be arranged to be released only by the combined or consecutive operation of controls located on both components, or the locking means may be released automatically. The locking apparatus may be retracted in flight.

Aeroplanes—General

417,813. *Improvements in or relating to Slinging Gear for Aircraft.* The Blackburn Aeroplane and Motor Co., Ltd., Seaplane Base, Brough, Yorks, and Petty, G. E., Pantiles, Brough, Hull, East Yorks. Dated, Aug. 17th, 1933. No. 22,970.

In order to reduce the stresses on the aircraft structure caused by the ordinary slinging arrangements, it is proposed, in the case of a normal biplane, to use a rod as a suspension member which passes through the top plane and is attached to a strong bulkhead in the fuselage. Where the suspension member passes through the upper plane a tube is fitted which is braced to the outer section. The suspension member carries a concentric fitting, which is a close fit in this tube.

Airscrews

418,109. *Improvements in or relating to Airscrew Propellers or the Like.* Perrin, E. A., 9, Rue des Charmes, Le Vesinet (Seine and Oise), France. Convention date (France), March 17th, 1933.

This specification refers to what is described as an airscrew propeller or the like mounted on a shaft to which it is capable of being locked so as to be capable of acting as a sustaining plane or from which it can be released so as to permit of its rotation about the said shaft, while the incidence of the blades can be varied when the propeller is adapted to rotate. Detailed claims are made for mechanism devised for the purpose of constructing the propeller.

Control of Aeroplanes

417,161. *Improvements in or relating to Means for Controlling Aircraft.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Hollis Williams, D. L., Hillside, Swakeley's Road, Ickenham, Middlesex. Dated, Nov. 18th, 1933. No. 32,218.

In order to preserve the " feel " on a control operated by a servo flap, the servo flap is operated by a link from a lever pivoted on a member rigidly secured to the control member. The arrangement is such that any load applied by the pilot is applied to the flap and also to the control, while the servo flap has a mechanical advantage in the leverage.

417,487. *Improvements in or relating to the Control Surfaces of Aircraft.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Brown, A. C., 109, Cleveland Road, Ealing, London, W.13. Dated, Nov. 17th, 1933. No. 32,127.

In order to improve the balance of aircraft ailerons of the type where the hinge centre is behind the leading edge, it is proposed to use a type of aileron of which the camber may be varied by making the nose of the aileron movable. When such an aileron is depressed for the purpose of increasing lift the position of the forward part remains substantially unchanged, and when raised for differential action its nose projects into the region below the lower surface of the wing, thus attaining the desired result. The nosepiece of the aileron is moved relative to the ailerons by means of a link controlled by a nut on a threaded rod. This threaded rod is rotated by means of a drum round which is wound a cable which is operated by the control mechanism. Methods of varying the gearing of this cable are described and a means of closing the gap resulting from the relative motion of the nose and tail portions of the aileron by means of sliding members are also referred to.

417,658. *Improvements in Navigational Steering Systems.* Bendix Aviation Corporation, 105, West Adams Street, Chicago, Illinois, U.S.A. Convention date (U.S.A.), April 6th, 1934.

It is stated that the value of an efficient automatic steering system depends on its capacity to anticipate the deviation of a craft from its course and to check the rudder at the right moment so as to prevent swing. The angular moment is a function of two factors, the angle of departure and the rate of departure. The former is determined by a compass and the latter by a gyro turn indicator. The desired effect can be obtained by combining these two factors. The compass proposed is of the electrically-operated repeating type and the servo unit comprises a pair of bellows operatively connected to the control member or rudder of the craft which is to be steered, and the interior of said bellows is connected to a suction supply and arranged so that normally the atmosphere tends to compress both bellows equally, thus keeping the rudder in a central position, and upon operation of the turn indicator and/or the compass, due to deviation off the course, a leak in one or the other of the bellows is opened to the atmosphere thereby causing its associated bellows to collapse and thus operating the rudder.

417,898. *Improvements in or relating to the Controlling Mechanism of Aeroplanes.* Fairey, C. R., Cranford Lane, Hayes, Middlesex. Dated Oct. 26th, 1933. No. 29,733.

It is proposed that the trailing portions of the ailerons of an aeroplane being variable camber gear shall be split into upper and lower parts and each of the lower parts is arranged to be depressed at will relatively to and simultaneously with the depression of the aileron of which it forms part without interfering with the capability of depressing said lower parts independently of movement of the

ailerons of which they form parts. The lower parts of the ailerons may be interconnected with means for forming slots in the wing. The operating means, which consists of pulleys and cords operated by nuts moved by threaded rods, is described in detail.

418,542. *Device for Automatically Regulating the Altitude of Aircraft.* Siemens and Halske Aktiengesellschaft, Berlin-Siemensstadt, Germany. Convention dates (Germany), Nov. 26th, 1932, March 18th, 1933, and April 7th, 1933.

It is proposed to control the flying altitude of aircraft by altering the propelling force. For this purpose it is proposed to use a combination of an altimeter control with a hand control and to damp the apparatus so as to prevent hunting, and it is stated that the damping can be well effected by means of a rate of climb indicator. The instrument measuring the rate of change of the altitude of the aircraft may be a so-called variometer or any other measuring instrument not having the slowness of response of the variometer, for example, a pendulum, measuring the vertical accelerations and having a very long oscillation period. A pendulum measuring the true vertical accelerations may be used additionally to the above named instruments measuring the rate of change of altitude.

418,499. *Improvements in or relating to Automatic or Semi-Automatic Pilot for Aircraft.* Sperry Gyroscope Co., Inc., Manhattan Bridge Plaza, Brooklyn, New York, U.S.A. Convention date (U.S.A.), July 21st, 1933.

It is stated that it has been found that the gyro vertical or artificial horizon will not maintain uniform level flight on account of the fact that rising and descending air currents may change the course of the aeroplane in elevation without affecting its fore and aft level. It is therefore proposed to employ a gyro vertical and an expansible container which can be closed to the atmosphere at will, and including means originated by the expansion or contraction of the chamber in accordance with any change in atmospheric pressure for altering the relation between said gyro vertical and the craft to maintain level flight. The proposed device resembles a statoscope and may operate through a differential link in the follow up system leading to the gyroscope. Preferably a novel differential air link means is used to operate the variable link.

418,540. *Improvements in or relating to the Control Surfaces of Aircraft.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Hollis Williams, D. L., Hillside, Swakeley's Court, Ickenham, Middlesex. Dated Nov. 23rd, 1933. No. 32,812.

It is proposed to employ, in connection with the elevator control of aircraft, two servo flaps mounted one on each side of the elevator. One flap, which is smaller than the other, is used to assist the aircraft to maintain trim and is actuated by the pilot through a screw and link gear. The other and larger flap is used for normal control purposes in the usual way for reducing the moment required for operating control surfaces.

Engines

417,334. *Improvements in Liquid Coolers for Aircraft or other Vehicles.* The Bristol Aeroplane Co., Ltd., Fedden, A. H. R., and Mayer, F., all of Filton House, Bristol, Gloucester. Dated, April 7th, 1933. No. 10,456.

This invention refers primarily to the cooling of the lubricating oil of an air-cooled radial aeroplane engine, and the cooler proposed forms the front portion of a circumferential cowling of the type known as a Townend ring. The front portion of the ring is formed by a number of oval tubes with their least diameter radial and the oil to be cooled is pumped through these tubes. The

specification describes in detail a method of applying the invention and methods of feeding the oil to the tubes, and a pressure release valve is also described. It is proposed to support the apparatus by plates attached to the cylinders of the engine.

418,721. *Improvements in Aeroplanes Driven by Constant Pressure Gas Turbines.* Aktiebolaget Milo, Kungsgatan 32, Stockholm, Sweden. Convention date (Germany), Feb. 15th, 1933.

This invention relates to an aeroplane propelled by a constant pressure gas turbine, the exhaust gases of which are exhausted towards the rear at so high a velocity that their recoiling effect sustains or wholly replaces the propeller. The gas turbine described consists of a turbine compressor followed by a combustion chamber in which the compressed air is heated, which is followed by a power generating turbine, the exhaust of which is directed rearwards. If no propeller is fitted the turbine will only perform the compressor work, all the propulsion being effected by the rearward ejection of the gases. This arrangement is preferred for high-speed aircraft. For slow-speed aircraft the turbine may drive a propeller, the ejection of the gases rearward producing an additional thrust.

Helicopters

417,093. *Improvements in Aircraft.* Rigby, F. G., and Rigby, P. N. R., 25, Stubb's Gate, Newcastle, Staffs. Dated, Jan. 11th, 1934. No. 1,045.

This specification describes an aircraft adapted for forward motion, direct lift and hovering, comprising two tractor screws on longitudinal axes on opposite sides of a fuselage, two fans adapted to be coupled to the tractor screws when direct lift is required, and a third fan at the forward end of the machine to check forward motion when hovering.

417,581. *Improvements in Aircraft.* N.V. Instituut voor Aero and Hydro-Dynamick, 19, Regubersgracht, Amsterdam, Holland. Dated, Feb. 2nd, 1933. No. 27,152. (Patent of addition to No. 417,504. Convention date (Germany), Feb. 2nd, 1932.)

This specification describes a flying machine with rotary wings which are articulated for free oscillatory movement to a swash member connected with the fuselage for rotating and free tumbling motion characterised by the fact that means are provided for preventing oscillatory movements of said wings in planes other than the planes containing the axis of rotation of said swash member. The swash member is mounted for rotation on a vertical shaft and the wings are articulated to radially extending journals connected with said shaft by links which prevent rotation of the journals about their axes.

418,212. *Improvements in or relating to Helicopter and Rotating Wing Aircraft.* Coats, A. G., Gloucester House, Park Lane, London, W.1; Rutherford, W. V. d'A., of the same address; Hafner, R., Mantlergasse 47, Vienna 13, Austria; and Nagler, Rennweg 59, Vienna 3, Austria. Dated March 21st, 1933. No. 8,555.

The main objects of this invention is to increase the stability and manœuvrability of helicopter machines, to improve the controllability of rotary wing aircraft to reduce the drag of such aircraft and to enable helicopter machines to be transformed instantly at will into auto-rotative wing aircraft and vice-versa. The blades of the lifting screw are rotatably mounted about their individual axes and a control column is universally mounted at the centre of the windmill. There is also a spider which is connected by radius rods to the blades for the purpose of controlling incidence. The blades are braced against centrifugal force by

means of a triangular bracing and they are normally free to take up a position in which centrifugal force balances the lift. It is proposed that the machine shall rise from the ground as a helicopter and that when height has been attained it is to be propelled horizontally either by inclining the lifting propeller or by clutching in a traction propeller. When the speed is sufficiently great the lifting propeller may be disengaged from the engine and allowed to turn by autorotation.

418,674. *Improvements in or relating to Rotating Wing Aircraft.* Coats, A. G., Gloucester House, Park Lane, London, and Hafner, R., Mantlergasse 47, Vienna 13, Austria. Dated, April 25th, 1933. No. 11,991.

This specification refers to aircraft which are supported in the air either by helicopter lifting screws or by rotors of the autogiro type in which the blades are flexibly connected to the hub. It is proposed to arrange that the angle of inclination of the blades is variable and under the control of the pilot of the aircraft. The blades carry, near their root, a lateral arm which is connected flexibly to a separate arm attached to the hub, so that when this arm is moved up and down the shaft the incidence can be varied. The hub can also be inclined axially by the pilot.

418,698. *Improvements in or relating to Rotative Wing Aircraft.* Coats, A. G., Gloucester House, Park Lane, London, W.1, and Hafner, R., Mantlergasse 47, Vienna 13, Austria. Dated, Aug. 25th, 1933. No. 23,645.

The object of this invention is to enable the angle of the blades of the lifting screw of a helicopter or autogiro aircraft to be easily and quickly changed by the pilot from a positive or negative value or vice-versa without losing the speed of rotation so that a helicopter may be flown as an autogiro. The blades may be connected to the hub by a torsionally flexible radial member which may be mounted inside the arm of the blade, and there is also a universal joint which permits the blade to flap up and down and also to have a limited motion in the plane of rotation. There is also provided means by which the pilot can vary from the cockpit the incidence of the blades. Several different arrangements are shown and described in which the torsionally flexible member which resists the centrifugal pull of the blades may be either inside the blade, external to it, or in duplicate.

Instruments

418,377. *A New or Improved Gyroscopic Instrument for Aircraft and the Like.* Dove, J. S., Hale House, Ockley, Surrey. Dated, April 24th, 1933, No. 11,924, and Dec. 11th, 1933, No. 34,829.

This invention consists of a gyroscopic instrument which gives an indication of the amount of turn and is capable of giving this indication in respect of either or both of any two axes. It may also be used to control servomotor devices which, in their turn, may act on the controls of the aircraft. It consists of a gyroscopic rotor with two axes of freedom or partial restraint and is drawn by the direct exposure to the air through which the aircraft is moving. Changes in the direction of this air flow will affect the rotor gyroscopically. The rotor may be provided with a rim to facilitate indications from direct observation or remote reading mechanism may be used. A mechanism is provided to enable the rotor to be re-erected or to be held if desired. Two or more rotors may be used together. Assuming that the aeroplane yaws to the right, the rotor, by virtue of its gyroscopic action, will remain in the plane of the original direction of flight and that the ring is displaced in regard to the fixed portions of the mechanism. If the aeroplane drops a wing the ring remains edge on to the pilot, but indicates the angle of bank. An indication of course is also given, due to the effect of a side wind on the exposed portion of the rotor. There is

also an aerofoil surface angularly moving with the rotor, but not rotating, which applies aerodynamical forces so as to modify gyroscopic influences.

Miscellaneous

418,258. *Improvements in or relating to Locking Devices for Boards or Similar Structural Elements.* Aktiebolaget Batpatent, Upsala, Sweden, and Engman, K. V., Börgegatan 45, Upsala, Sweden. Dated, Nov. 10th, 1933. No. 31,349.

This invention describes a method of attaching together members such as the slats of a vat with tensional wires and it is stated to be a suitable method of forming an aeroplane fuselage. The tensioning wires run through the members to be attached and are tensioned by nuts at one or both ends of the wire, thus squeezing the slats closely together. Locking methods for preventing the slacking off of the nut are described.

418,221. *Improvements in Hydraulic Control Apparatus.* Boothby, F. L. M., Capt., R.N. (ret.), of 4, Woodvale, Cowes, and Thompson, J. A., of Pangani, Egypt Battery, Cowes. Dated, April 19th, 1933. No. 11,482.

This is a method of operating aircraft controls by means of two double acting hydraulic cylinders interconnected by pipes so that manual movement of the piston in one produces a corresponding movement in the other. In the pipeline between these cylinders is fitted a device for making up loss of fluid, consisting of a reservoir under slight pressure produced by a spring-weighted piston and also a special cock which can be used for locking the controls in any desired position.

418,396. *Improvements in or relating to Tail Supports for Aircraft.* The Blackburn Aeroplane and Motor Co., Ltd., Seaplane Base, Brough, Yorks, and Petty, G. E., Pantiles, Brough, Yorks. Dated, Aug. 2nd, 1933. No. 21,692.

This specification describes a tail support for aircraft which is intended to take the place of the usual trestles when the aeroplane is to be adjusted or repaired. The tail support may be permanently attached to the fuselage of the aeroplane and consists of two tubes in V formation, folding when required under the fuselage. The tail support is completed by a third tube, also arranged to fold, the three tubes when in use forming a pyramid. The height of the tail of the machine from the ground may be varied and various locking devices are described.

419,310. *Hydraulic Control Gear.* Hele-Shaw, H. S., and Beacham, T. E., both of 64, Victoria Street, Westminster, S.W.1. Dated May 13th, 1933. No. 13,926.

This specification describes a hydraulic control mechanism which may be used for the remote operation of carburettor controls in aircraft or for either purposes such as steam valves or ships' telegraphs. It is characterised inasmuch as there is only one pipe containing liquid connecting the controlling and controlled element, the return motion of the controlled element being performed by springs. Both elements consist of pistons in cylinders, the latter being connected by the pipe and being filled with non-freezing fluid. The operating levers which move, or are moved by the pistons, carry cams which are acted on by springs, the cams being designed so that the spring load is constant. The spring load is equal for both cylinders. A special valve operated by the controlling piston is provided for the replenishment of fluid in the system; this valve communicates with a reservoir.

418,486. *Improvements in or relating to Blade Wheel Propellers with Oscillating Blades.* Voith, W., Voith, H., and Voith, H., of J. M. Voith, Heidenheim, Brenz, Wurttemburg, Germany. Convention date (Germany), March 18th, 1933.

The blade wheel propeller described has oscillating blades which are made to oscillate by means of a motion communicated by a fixed pivot which is located out of centre with the rotating centre. The motion is communicated by means of rocking levers and shafts connected to cranks on the blades themselves so that the blades oscillate when the apparatus is rotated.

Model Aircraft

418,464. *Improvements in or relating to Model Watercraft and Aircraft.* Gordon, C. B., Monach, Rockcliffe, Dalbeattie, Kirkcudbrightshire, Scotland. Dated, May 10th, 1933. No. 14,472.

This specification describes a method of constructing a model boat in which V-section forms are combined with suitably shaped longitudinal members and are afterwards covered by a plastic material or in any other suitable way. The construction of the fuselages of model aircraft in a similar manner is referred to.

Parachutes

419,218. *Parachute Closure.* Popelák, J., 68, Kralovska, Prague X, Czechoslovakia. Dated, May 10th, 1933. No. 13,653.

This specification refers to an opening device for parachutes and can be so arranged to provide for automatic opening by means of a cord attached to the aircraft and also for manual opening by means of a further cord. The parachute closure is effected by means of two angle plates which tend to fly apart by means of a load applied by rubber in tension, but which are normally held in approximate contact by two studs which are retained in position by pins at each end. The pins at one end of the two studs are arranged to be withdrawn simultaneously automatically, and the pins of the other end of the two studs can be withdrawn manually. Either can then, when withdrawn, cause the opening of the parachute.

418,209. *Improvements in or connected with Parachute Equipment.* Irvin, L. L., Kingsweir, Broadway, Letchworth, Herts. Dated March 21st, 1933. No. 8,539.

This invention is concerned with a method of locating the release device of parachutes to be arranged so that it may be conveniently operated. A wide supporting member is provided for the release device or spring which is secured to the harness, preferably about the wearer's waistline. This supporting member is provided with a pocket for the ring which is tapered so that a slight resistance is offered to the ring being pulled out, so as to prevent accidental release. Such an arrangement prevents interference with the release device by the airman's clothes.

Undercarriages

418,468. *Aeroplane Undercarriages.* Sir W. G. Armstrong Whitworth Aircraft Co., Ltd., and Lloyd, J., both of the Company's Works, Whitley, near Coventry, Warwickshire. Dated Nov. 8th, 1933. No. 31,066.

This invention consists of a retractable undercarriage for aircraft in which each wheel of the undercarriage is fitted on a shock-absorbing strut, the top end of which is hinged to, say, the front spar of a monoplane wing and arranged to swing backward. When the undercarriage is in use it is prevented from

swinging backwards by a radius rod extending rearwards to the wing. This rod carries at its upper end a trunnion block carried by a threaded shaft extending to the support of the front strut, and on turning this shaft the radius rod is moved to a position closely parallel to the main strut, when the latter and the wheel can be drawn up into the wing.

CORRESPONDENCE

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

Dear Sir,—In recent lectures before the Society I have noticed an increasing tendency for invidious and sometimes rather biassed comparisons to be made between competing interests. Might I put forward a plea that when comparisons are necessary they should be made in a strictly scientific spirit. The object of the Society is surely to promote true knowledge rather than to give a one-sided outlook on any problem.

When the case for some development is put before an audience I feel very strongly that a true impression can only be created if the case against it is given at the same time, and a completely impartial attitude maintained throughout.

Yours faithfully,

HAYNE CONSTANT.

REVIEWS

The Problem of Noise

By F. C. Bartlett. Cambridge University Press. Price 3/6.

This book consists of a clear statement of the problem of noise as it is understood to-day, and is written in a way which will enable it to be understood by those who are not scientists. There is only one short reference to this problem in connection with aircraft, and that is confined to engine noises.

The experiments described in which attempts have been made to estimate the effect of noise on mental workers are interesting, and it would appear, generally, that the greater the interest of the work the less the subject is affected by the noise. But the subject is probably interested in the experiment as well as in the task; as he cannot usually be prevented from knowing what is going on it follows that his difficulty in concentration on one thing is thereby increased. Once his attention on his work is allowed to wander his efficiency is necessarily reduced. I have known chess players who were perfectly oblivious to all noises when engaged in a game to such an extent that it is permissible to believe that even a revolver shot would not be noticed, but it may even be that a noise of which a person is not aware may affect his mental processes adversely.

Some of the complaints of aircraft noise made by passengers may be due to a state of mental alertness produced by a novel experience. If the passenger could forget that he was flying and concentrate on a book or the scenery much of the noise might be unnoticed.

Those who are interested in a subject which is becoming more important every day should read this book.

Jane's All the World's Aircraft

Edited by C. G. Guy. Published by Sampson Low. Price £2 2s. 0d.

The 1934 edition of this well known work does not differ in arrangement from its predecessors. The high standard one has become accustomed to in previous editions is well maintained and the book still is the one invaluable work of reference on the progress of aeronautical design and construction.

Since the last issue was published alterations have occurred in the position of the various countries in the matter of the number of different types manufactured in each. Last year the list was headed by France with 142; this year the United States takes the lead with 144, France dropping to second place with 118. Last year Great Britain was second with 124 types, this year she is third with 111. The other countries produce much smaller numbers, the next being Italy with 54. This analysis can be considered as indicative of the amount of aeronautical development taking place in the various countries.

With regard to design, there is no doubt that the monoplane is making headway. In Great Britain it is noticeable that the biplane construction is nearly confined to the older firms in the industry, the newer and smaller firms confining themselves almost entirely to monoplanes. But a monoplane, the Fairy Hendon, has forced its way into that stronghold of biplane construction, the Royal Air Force, and may be the forerunner of many others.

The most popular type of monoplane is the low wing. In light aeroplanes it has the important advantage of improving the pilot's view and in both large and small machines the thick wing near the bottom of the fuselage forms a convenient receptacle for the folded chassis. Most of these machines are of the

cantilever type, but when a high wing design is preferred it is more usual to support the wing with struts. It is obvious that much more attention is being given generally to clean design with the result that speeds are increasing without increased horse-power. The culminating point in this development seems to be reached to-day in such types as the de Havilland "Comet" and in certain American transport aircraft, of which the "Douglas" is typical. One small French light two-seater aeroplane with a 140 h.p. engine even claims a top speed of 196.3 m.p.h. on a power loading of 16lbs. per horse-power. Such a claim would have been regarded as incredible in any previous year and even to-day it requires substantiating.

With regard to engines, the well known types remain similar to previous models, but there is a distinct tendency to the further development of supercharging, and in the United States to the production of double-row radials. This latter tendency is doubtless connected with a demand for more power. The Diesel does not seem to have made much further progress, though a most interesting engine of this form designed as an air-cooled radial is now made by the Bristol Co. and the Junkers types are being manufactured in Great Britain by the Napier Co. On the other hand, the type seems to have been abandoned temporarily in the United States, and there is little evidence that it is attracting interest in other countries. A sleeve valve radial petrol engine has been produced in Great Britain by the Bristol Co. This development is of great technical interest and the performance of the new engine is full of promise.

Aeronautically, there is no doubt that the past year has been one of great progress in design and construction and there is every evidence that this progress is continuing. It is therefore probable that the outstanding performances of to-day will be considerably surpassed in the immediate future.

Seaplane Design

By W. Nelson. The McGraw Publishing Co., Ltd. Price 21/-.

This book deals with the naval architectural side of seaplane and flying boat design rather than the aerodynamical. The author is a Lieutenant-Commander (Constructional Corps), U.S. Navy.

It is peculiar for the fact that all work on seaplanes which has been done outside the United States is almost completely ignored. In fact it would seem as if Lieut.-Comdr. Nelson does not know of the tremendous amount of work which has been done on this subject in this country and of the bearing of this work on some of the problems he discusses. Take, for instance, the subject of porpoising. The book states: "Owing to some cause which has not been identified satisfactorily, some floats porpoise in the take-off run," and has no suggestions to make as to how this may be avoided. Is it really possible that he has never heard of R. & M. 1493 or of the work on this problem which has been carried out in British tanks during the last 15 years or so? In this country the characteristics of hull form, which tend to increase or reduce porpoising, are quite well known.

Again, there is no recognition of the fact that at high speeds the lift of a stepped hull is dynamic as opposed to the static lift given by displacement. The author's explanation of the effect of a step is: "At higher speeds an inverted waterfall is produced which gives enough break in the flow so that the suction effect is reduced to reasonable proportions."

This book suffers too much from a limited outlook to be a good text book, though it is of interest owing to the insight it gives into the American school of seaplane design. No book on any major aircraft problem can possibly be satisfactory to-day if the author is determined to ignore all work except that carried out in his own country.

The 579th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

The first meeting of the 1934-35 session was held at the Royal Society of Arts, John Street, Adelphi, London, W.C.2, on Thursday, October 18, 1934.

The chair was taken at the opening of the meeting by Mr. C. R. Fairey, the retiring President, who introduced the new President, Lieut.-Col. J. T. Moore-Brabazon.

Mr. C. R. FAIREY: The Royal Aeronautical Society could justly be considered the most important society of its kind in the world, and was old enough already to have a historical tradition of its own. The honour of being elected to the Presidency was one which he himself very deeply appreciated, since it could be regarded as the most honoured post that one could hold in aviation. In relinquishing that post and apologising for his own short-comings, he desired to thank very sincerely all those people who had worked so loyally and so hard for the Society during the term of his Presidency. The Council as a whole had done yeoman service, and he was pleased to note that the attendance at the Council Meetings had been higher than those of any other committee or council on which he was privileged to serve. Particularly would he like to mention Mr. Wingfield (the Solicitor), Major Kennedy and the Finance Committee, Mr. J. E. Hodgson (the Hon. Librarian), and Mr. Wimperis, who had not only done a great deal in deputising in the Presidential Chair on many occasions but had been responsible for the fact that the Air Ministry subsidy to the Society would be continued for the future. Last, but far from least, the President said he wished to refer to the deep debt of gratitude that was owing to the Secretary, Captain L. Pritchard, to whom more than to any other man the Society owed its present prestige and relative prosperity. Although Presidents might get some of the credit, it was always the Secretary who did the work.

Continuing, the President said that in introducing his successor he would spare him the embarrassment of dealing in detail with his career and his many achievements. At the same time, it should be placed on record that the Royal Aeronautical Society had elected as its new President the first Englishman ever to fly. That had been a much debated question, but it was now beyond doubt. It was in December, 1908, that the first flight was made in France, and in March, 1909, Lieut.-Col. Moore-Brabazon was the first to fly in England. Moreover, he flew the first circular mile, on a British machine, on October 30, 1909. Certainly, Lieut.-Col. Moore-Brabazon must be an extremely good pilot, since he has survived the very weird apparatus which he took into the air in those days! After distinguished service with the Royal Flying Corps during the war, and with his long continued and sustained interest in avaiation, Lieut.-Col. Moore-Brabazon was in Parliament to-day aviation's best and strongest friend. That, added Mr. Fairey, he could testify to from his own knowledge. Moreover, Lieut.-Col. Moore-Brabazon had held under the Government, posts in the Ministry of Transport, and, judging by the antics of his successor, it was perhaps to be wished that he was there to-day! Lieut.-Col. Moore-Brabazon had, moreover, many other achievements than in aviation. He had on more than one occasion been the Cresta champion, but that did not inspire him personally with so much respect as the fact that he had taken up the game of golf and had become scratch within a year. Nor, indeed, had Lieut.-Col. Moore-Brabazon lost his liking for weird appliances. As a yachtsman he was very well known, and only this

year had produced a most wonderful yacht with which he had sailed the seas, and had fitted a type of autogiro very successfully to a standard Redwing. As a Fellow of the Society, Lieut.-Col. Moore-Brabazon was one of its oldest, since his membership dated from 1909. Personally, said Mr. Fairey, he considered the Society had acted very wisely and had made a very sound choice in electing Lieut.-Col. Moore-Brabazon as President, and, with knowledge of his abilities, that office could be handed over with the greatest confidence.

The chair was then taken by Lieut.-Col. Moore-Brabazon.

The PRESIDENT: He must first thank Mr. Fairey for the very kind remarks he had made about himself, although perhaps he was not so thankful to him for having dragged out incidents of his past which he sometimes liked to forget! Continuing, he said that the peculiarity of the Society was that the older it became the more vigorous it became; it was to be wished that that was a peculiarity also of human nature, but unhappily it was not. The Society had had a very distinguished line of Presidents. Everybody would remember Lord Weir, Sir Sefton Brancker, Lord Sempill and finally Mr. Fairey, and he was not at all sure that it was not something of a gamble to elect himself. Certainly he regarded his task the more difficult because of the distinguished people who had occupied the Presidency before him. Speaking of Mr. Fairey, he said that he must have obeyed the old adage of going to bed early and rising early, because he was healthy, wealthy and wise, and one could not ask for anything more than that in this life. Certainly the Society did a very wise thing when they chose him, because one could not be in the presence of Mr. Fairey for long without realising that he was a man in whom it was impossible to have anything else than complete trust. Moreover, Mr. Fairey had done his duty as President of the Society in a most generous and able manner, and he could assure Mr. Fairey that all concerned with the Society had the greatest feelings of gratitude towards him, whilst Mr. Fairey himself should have the greatest satisfaction from the knowledge that during his period of office the Society had reached its high-water mark.

As to the reference made by Mr. Fairey to certain distant accomplishments of himself, Lieut.-Col. Moore-Brabazon said that in another fortnight it would be 25 years since he won the " Daily Mail " prize for flying a mile. For that he obtained £1,000, which seemed a very good reward in those days, but he could assure them that there was not a great deal in it when everything was taken into consideration. Nevertheless, he still remembered every incident and every single detail of that flight, and would certainly remember the anniversary 25 years afterwards, because through the kindness of the Members and Council of the Royal Aeronautical Society he had been appointed to what he considered far and away the most distinguished position one could obtain in aeronautics, namely, the Presidency of the Society.

Turning to the lecturer of the evening—Professor Pippard—the President said he was to lecture on a topical subject, namely, the training of the aeronautical engineer. Personally he wished that Professor Pippard could have trained him in his early days, because then he would now have been a much more useful person. Professor Pippard himself was trained at Bristol University, and his career during the war was well known. He was responsible for the strength of all aircraft, first under the Admiralty and then in the Air Ministry. Since then he had been Professor of Engineering in the University of Wales at University College, Cardiff, and at the present time was Professor of Civil Engineering at the Imperial College of Science of London. He was the leading authority on aircraft structures, and had published numerous memoranda on the subject in addition to being joint author with the Secretary of the Society of a standard work, namely, " Aeroplane Structures."

Professor PIPPARD: Before presenting the paper, he had already received one criticism upon it which perhaps he should deal with at once—particularly as that criticism came from the Secretary, who was prevented by tradition from discussion at a meeting. The Secretary, with great candour, had suggested that the views expressed in the paper might be all right from the point of view of the writer, since he was advocating a training for the aeronautical engineer such as he himself had received. Professor Pippard explained that this was not quite correct, and that, as a matter of fact, he regretted as regards many details that he was not trained along the lines suggested.

Professor Pippard then delivered his lecture.

THE TRAINING OF AN AERONAUTICAL ENGINEER

BY

PROFESSOR A. J. SUTTON PIPPARD,

M.B.E., D.Sc., M.Inst.C.E., F.R.Ae.S.

I. Introductory

It is with some misgiving that I come here this evening to lecture to this Society on the training of an aeronautical engineer. The subject is not one which I chose myself; indeed, I think that it is probably the very last which I should have selected to talk about, but the Council of the Society, for some reason which I have not yet been able to understand, invited me to deal with it. I rashly promised to do it, but now that the time has come to redeem that promise I feel that I ought to have refused and chosen a subject on which perhaps I could speak with a little more authority. I suspect, however, that the Council was anxious to obtain a discussion on a topic which to any Society is a very important matter and that I have been put up to serve as a target for your criticism in the hope that something useful may emerge from your comments rather than from my paper.

Compared with most other branches, aeronautical engineering is still young and it is, therefore, of fundamental importance that we, as a Society, should start on right lines when we are considering the training of future members of the profession. There is, I think, a tendency in all Societies for this matter to be considered as settled once and for all and crystallised in a series of rules which are then extremely difficult to modify. The formulation of such rules for the training of entrants to any Society is necessary, but I think they should be made as elastic as possible in order to admit cases in which there has been perhaps a considerable divergence from the standard routine.

I should like it to be understood, therefore, that any suggestions I may advance this evening are not hide-bound convictions, but intended primarily to stimulate discussion so that we may arrive at the best compromise as to what constitutes a normal or average process of training. Whatever rules the Society may lay down for the training of the aeronautical engineer, I sincerely hope that they will admit sufficiently wide variations in interpretation as may be necessary to cover the exceptional cases.

We are sometimes apt to speak of aeronautical engineering as though it were something distinct and separate from engineering as commonly understood. This, I think, is a mistake. It is impossible to dispense with the knowledge and experience gained in other branches of engineering, and although there must of necessity be a special technique and a special outlook in any particular branch, the fundamentals are the same for all. I believe this to be the right attitude to take and therefore many of my remarks will apply with equal force

to the training of engineers for whatever branch of the profession they are destined.

II. The Scope of the Inquiry

I have called my lecture " The Training of an Aeronautical Engineer," but this designation includes men of widely differing abilities and functions and it is necessary to be clear as to the distinction between them and the appropriate differences in their training. So long as engineering is an open profession, there is nothing to prevent anyone from assuming the title of engineer, and the fold which encloses those who take it is very wide. It is used to embrace all grades from the distinguished consultant to the most recently joined member of certain trade unions. I should like to make my definition rather narrower than this, but at the same time, I wish to include grades with different functions since the Society admits these different grades to its membership. May I then, for the sake of convenience in discussion, divide the people whom we have to train into the categories:—(1) Draughtsmen, (2) Works Engineers, and (3) Design or Research Engineers. All of these are essential to the successful production of aircraft and the training should be suitable to the requirements. They are not hard and fast divisions, but I think the designation will bring to mind the broad types of which I am thinking.

The qualities and training required for successfully carrying out the duties of these type classes are different. A first class works engineer may be an extremely bad draughtsman, and how many men engaged in aircraft manufacture would care to put some of our distinguished research workers in charge of their shops? These grades, therefore, are complementary to each other and the particular one in which an individual finally finds himself will be decided very largely by his mental outlook, provided always that his equipment in the way of training has been suitable. There is very little use in attempting to manufacture a competent member of any grade from a man who is mentally unsuited for the work involved, and no matter how much you try to train him you are bound to fail. You can try to pump mathematics and science into a man whose interests are in controlling a workshop; the result will be to bore him thoroughly and a large proportion of your effort will be wasted. It therefore seems to me that a grading in training is necessary not only to produce the best results from a technical point of view, but also from the economic standpoint. My meaning will perhaps be clearer when we come to a more detailed discussion of the training.

III. The General Scheme

The period of training of any engineer falls naturally into three divisions. The first period necessarily takes place at school. On leaving school the embryo engineer must obtain a scientific and technical training and also practical experience. This practical experience should, I think, be in the form of works training, at any rate for part of the time, although in some special cases certain types of research may profitably replace some of it. This will depend on the work which the engineer wishes to do when he has completed his training. The question of early education I shall leave for the moment, but one problem in connection with the technical and practical training has to be faced and that is the order in which these should be taken.

It is not so many years ago that scientific and technical training was considered by many engineers an absolute waste of time. I started my own practical training as a civil engineer immediately on leaving school with the intention of proceeding to the university after a year's experience of office work, and my chief told me with great emphasis that I should be wasting the three most valuable years of my life by taking this course and that the only way for an engineer to be trained was " to go through the mill." The process known as

going through the mill was the recognised method among the old engineers, just as at an earlier date it was with doctors, but a technical education is now generally considered vital and the problem to be settled is at what stage in the training it shall be taken.

There are three possible courses for the future engineer. He may, on leaving school, proceed to a university or technical college, following this by a period of practical training. He may invert the order and go into works immediately on leaving school, proceeding to the university later, or he may adopt the sandwich system, *e.g.*, study for a year at the university, spend the next in works, complete two further years at the university and then finish his works training. The sandwich system is in operation in one or two universities and colleges. An attempt to introduce it at Bristol University, however, did not meet with success and it has been dropped. In certain industrial districts, where the university can co-operate closely with neighbouring large engineering works, the system might be worked successfully, but in most places it is not a practicable one to adopt. We are left then with the question: Should the works training precede or follow the scientific? Opinions differ on this and there is much to be said for both sides. The advantage of taking the technical and scientific training immediately after school is that the candidate is able more easily to appreciate and understand the work. I must say that this has always appealed to me as a strong argument, since the day, when in Cardiff I used to get men who, after leaving school, had spent several years in the coal pits before taking their university courses. The agonies of mind which some of these men went through in grasping the simplest work was tragic. On the other hand, the argument for putting the practical training first is that the young man coming to the university has a much better understanding of what engineering means and can therefore appreciate the bearing of some of the work which he does in the university upon the practical aspect of the profession which he has chosen. I suppose there will never be complete agreement as to which is the better procedure but, perhaps because I did it myself, I am rather in favour of a particular form of the sandwich system. A year's practical experience immediately on leaving school, followed by the technical and scientific training, after which the practical training is completed, seems to me to be a reasonably satisfactory solution of the difficulty. The boy obtains a certain amount of insight into the meaning of his profession, but has not left his school work so far behind him that he has forgotten it seriously. In addition, his academic work is continuous as in my opinion it should be. The order of precedence, however, is not one which should be dictated by any Society as all the three cases which I have mentioned have produced equally competent and, probably, equally incompetent people.

IV. School

We can now discuss in more detail the process by which the raw material is run through the mill to produce the finished article. The raw material in our case consists of the school boy and the school girl. Until comparatively recently all the older branches of engineering have considered that boys only were suitable for manufacture into engineers, and even now it would be, I think, impossible or very difficult for a woman to join most of the senior engineering institutions. In the aeronautical world, however, we pride ourselves on being more liberal minded and the fact that we do allow women to become Fellows of this Society is an admission, I think, that the girl can, under certain conditions, also be manufactured into that noble product known as the Engineer. When talking about training, therefore, I shall in most cases include both sexes, and where I speak of boy I shall mean boy or girl. I do not wish to convey the idea that I consider all branches of the profession are as suitable for women as for men, but there can be, I think, no question that women are able to take and have

indeed already taken a valuable part in the development of aviation. There is sufficient evidence of this in the records of this Society and in the publications of the Aeronautical Research Committee.

We are rather apt to think that the manufacture of the engineer only begins when the boy leaves school, but the training received at school is, I think, of vital importance, unless we are going to take the view that an engineer is merely a form of robot with no moral or intellectual outlook outside his profession. May I therefore make a few comments upon the question of school education? In doing this I know I am skating on extremely thin ice and whatever I say I expect to draw your criticism.

The number of subjects included in the curriculum of the average school to-day is so large that a choice has to be made either by the school boy or by his parents, since there is no time to undertake the whole of them. Usually the choice has to be made between an early education consisting mainly of the classics, one confined largely to modern studies or, in some cases, one which is almost entirely scientific. The problem confronting the parent is, which of these courses he shall adopt for his son. There are two extreme points of view which I have heard expressed fairly recently. The first is that the child should study at school the subjects for which he will not have time when he takes up his professional training. The other point of view, which may be termed " the vocational," was expressed to me by a chemist, who said that if he had to educate a child of his own, he would only allow it to study German and chemistry. Both these points of view assume that it is known what profession the child is going to follow. Naturally this is an unusual and I think fortunate state of affairs, since a choice of education has perforce to be based on more general principles. To-night, however, we are assuming that we can foresee the future of the hypothetical child we are discussing and know that he will eventually become an aeronautical engineer. We must therefore look at the problem from that point of view and I suppose the general concensus of opinion would be in favour of sending the child to the science side of the school. I must confess that at one time this was my own view, but since I have had to face the problem in a practical way and to give it serious attention, I have come to the conclusion that in many cases, at any rate, it would not be the best course to adopt. Mr. Tizard, in a recent address to the British Association at Aberdeen, said that in his school days the desire to study science marked one as being not quite a gentleman. Those days are gone, but is it not true that something still remains engendered by the distrust and dislike of science? Although many of the schools in this country have very fine science departments, there is naturally still a very strong classical tradition and in some at any rate the quality of work done on the classical side appears to be better than on the others. The theory underlying the classical tradition, as far as I can understand it, is that the study of classics makes boys intelligent and more ready to assimilate other branches of learning when they have to study them. I believe I am correct in saying that modern psychology does not admit that intelligence can be created, that each of us is born with a certain amount of that desirable quality and that nothing we can do can alter it. It can be trained but not increased. It therefore looks as though the idea that the classics make a boy more intelligent is not exactly a tenable one, and I rather suspect that the truth of the matter is contained in a remark which came to me from a master in one of our public schools, who gave his opinion somewhat in these words:—" Under our present system all the most intelligent boys are persuaded to enter the classical side and we then turn round and say that it is the classical education which has made them intelligent!" I am not concerned this evening with a discussion of the relative merits of a classical and a scientific education as such, provided we could start on the assumption that all subjects were taught equally well. Things being as they are, however, there is no doubt that in many of our schools the best intellects

among the boys are to be found on the classical side and the result is that a boy entering that side will find himself pitted against keener competition and there will result a higher standard of work and achievement. Quite apart from whether the achievement is in itself valuable to him in his future life, there can be, I think, no doubt that the competition with good brains does give him a training of very great value. My own solution of the problem would be to let a boy do the classical work until he had qualified for his matriculation examination. To do this he naturally has to do a certain amount of mathematics and may also take elementary science, but these studies can, I think, receive more profitable attention at a later stage. After the matriculation stage has been reached the question of more specialised work must be tackled. You will see that I have discarded any idea of vocational training before the matriculation bar has been overcome. All this seems remarkably obvious and perhaps you are thinking that it is quite unnecessary even to discuss the point. I agree, of course, that it should be so, but it is not a generally accepted point of view and certain professional institutions even lay down the subjects in which a prospective entrant shall qualify at the *matriculation* stage, and we meet occasionally the strange position of a candidate for election who has actually obtained a degree in engineering but who cannot be admitted owing to the omission of a particular subject from his matriculation certificate. I hope very sincerely that whatever views the Society takes and whatever rules it lays down, it will at any rate leave the test of general education as wide as possible. We have no right to dictate what subjects should be taken at such an early examination.

Having obtained the matriculation qualification our budding engineer now has to consider his further training, and for convenience I shall take next the question of technical and scientific training. How and where this training will take place depends very largely upon the age at which the candidate passes matriculation. If he has done it at a reasonably early age, say from fifteen to sixteen, he is too young and immature to proceed direct to a university or technical college, and it is becoming increasingly common for such boys to remain at school for a further two years and to take the Higher School Certificate of one of the examining boards. This course, which I strongly favour, allows the boy to study the particular group of subjects which will be of value to him in his university course and he would probably take chemistry, physics and mathematics. If he obtains this certificate he will be exempt from practically the whole of the intermediate course in an engineering school, and he will be allowed to enter the second year course at once. It is usual to ask him to supplement his knowledge of these pure science subjects by doing some elementary machine drawing, which is normally done in the first year course at the university. There is, however, a growing body of opinion which would recognise the Higher School Certificate for complete exemption from the engineering intermediate examination and I feel there is much to be said for this view. The boy who does not matriculate until he is seventeen would probably, as conditions are at the moment, enter the university at once and his first year would be spent in doing much the same work as the boy we have just been discussing has done while at school.

V. Scientific and Technical Training

We now come to one of the most important parts of the training of the engineer—that is the scientific and technical side of his work. We have reached the stage where the boy or girl has left school with the necessary qualifications to enter an institution which will provide this training. For certain of the grades, which I have for convenience included in the title of aeronautical engineer, it is perhaps possible to dispense with a full time course at such an institution, but unless this is obtained the chances of rising to a position of even minor importance are very limited except in very rare cases of exceptional ability. If it is possible,

therefore, I should say without hesitation that any aspirant to the title of aeronautical engineer should consider a full-time course in a university or technical college to be an essential part of his training. Some years ago the majority of young engineers would have found this extremely difficult to achieve, since the number of places at which such instruction could be obtained was limited, but at the present time there are such a large number of colleges giving sound courses in engineering well distributed throughout the country that this argument does not apply. I have, by mentioning both, suggested a distinction between a university and a technical college and perhaps I should make this rather clearer. In addition to the universities in this country, which are institutions having power to grant their own degrees, there are a large number of technical colleges which have not that power, but which prepare students for professional work in engineering. These technical colleges vary considerably in scope, equipment and in the attitude adopted towards their work. Some of them give as good a technical training as can be obtained in university departments. Others of a smaller type do not pretend to carry the technical training to the same standard, but are content to give such technical knowledge as is useful to the draughtsman and mechanic who wishes to attend evening classes. A great distinction between a university engineering department and the corresponding department in a technical college is, as I have mentioned, the fact that the first institution has control of its own degree examinations while the second must prepare for the examinations of institutions which grant external degrees, such as London, or for the examinations of the professional institutions. This means that teachers in a university are freer to teach what they wish in their own way than those in colleges bound by syllabuses over which, in many cases, they have not the slightest control. This, I think, must necessarily affect the point of view adopted in the instruction given and the university scores heavily on this ground.

Before I discuss the question of the curriculum of the young engineer, I should like to say a few words on the function of the university. The part which the institution should take in the training of the engineer is one upon which views diverge rather largely. Some institutions profess to train the engineer, meaning that when the young man has taken his degree or diploma at that institution he is fitted to start work as an engineer. I am afraid that most of the universities are guilty tacitly, at any rate, of suggesting this when they call their departments devoted to this technical work, departments of engineering. I do not for one moment believe that there are many teachers of engineering in the universities who believe that they can, within the four walls of the university, produce the fully fledged engineer, but unfortunately the student often thinks that when he has taken his degree he will be qualified to receive large financial rewards for his skill and ability in the profession. On the contrary, there is at any rate a large body of teachers who believe and act upon the belief that their function is to teach engineering science. As far as I know only one English university, namely, Oxford, has the courage or honesty to call its department the Department of Engineering Science. My own view is that in this respect Oxford is right and that it would avoid considerable misconception and possible heart-burning if all the Universities were frank and followed that example. It may perhaps appear to the young engineer that to spend three or four years of his life doing science is a hard prospect, but when one considers that in most cases the only time when he will have the opportunity and possibly the desire to study the scientific bases of the work upon which he is going to be engaged for the rest of his life is during those three or four years at the university, I think it will be agreed that it is not too large a proportion of a lifetime to be spent in fundamental work. This is a point which I think may provoke some discussion, so that I am going to state categorically that in my opinion the university years should be devoted to the study of engineering science with as little emphasis as possible on the practical aspects of the work.

There is a further important question which deserves discussion. I have spoken so far of engineering courses without any emphasis on the aeronautical side and this is the point with which I should now like to deal. Should we train our young aeronautical engineer at this stage, that is for the first three years in the university, on broad lines of engineering science or should we attempt to specialise and introduce him to aeronautical work? Let me make my own position clear at the outset, before I start to discuss the point. I am of the opinion that the three years spent by the young aeronautical engineer in the university should be devoted to general engineering principles without any special reference to aeronautical work. As I mentioned at the beginning of this lecture, aeronautical engineering is only a branch of the profession, and although it is a highly technical branch the foundations of it rest on the same scientific principles as those upon which mechanical, electrical and civil engineering are built. At the beginning of a university career three years seem a long time to be spending on general work, but those of us who teach students know how lamentably short it is for our needs. The specialist parts of aeronautical engineering science should, in my opinion, be relegated to a fourth year or post-graduate course. Perhaps it may surprise some of my audience to hear me speaking of a fourth year course in connection with a university degree. It has been found, however, by most universities that three years from the date of matriculation to the award of a degree is insufficient time to cover the necessary essential groundwork for an honours degree in engineering. Several of the provincial universities have extended their course to four years, the first three years being sufficient to enable a student to obtain a pass degree, the fourth year being required if he wishes to get honours. Even in universities which have not adopted this system the difficulty is being felt, and I know that in some, at any rate, methods are being considered for solving that difficulty. As regards the aeronautical engineer, therefore, it seems to me we have two alternatives:—(1) His degree should be taken in the same subjects as the candidate who is preparing for the other branches of the profession, or (2) a completely new and separate course must be founded for this branch. If the second course is adopted a number of important subjects must be jettisoned and I am, as I said before, emphatically in favour of the first alternative. Furthermore, the specialist subjects of the aeronautical engineer, for example, aerodynamics and the theory of aeronautical structures, are essentially too difficult to be taken immediately and must be preceded by a foundation of other work. Now I do not wish to be misunderstood in this matter. I should not rigorously exclude from the course any reference to the motion of air or the behaviour of bodies in air, neither should I feel that I was doing wrong if in my lectures on the theory of structures I introduced examples drawn from aeronautical practice. Quite the contrary; I consider that aeronautical engineering has now reached the stage when it can claim to take its place with the other branches, and the teacher of engineering should feel just as free to give, as an example of a stress diagram, the wing of an aeroplane, as our old friend the French truss. In fact, I think he ought to take this view and in more advanced lectures on theory of structures attention should be devoted to those special problems, such as the effect of flexibility, which are almost peculiar to aeronautical engineering. You see, if you adopt the view that we should teach engineering science in a university and not engineering technique, these important problems are legitimate training for any engineer. Whether he will use the particular work in his later professional practice is of no concern to the teacher and of no particular importance. The training and the fundamental knowledge is what matters and not the application of it. That will come later.

After these generalisations it will be advisable to make definite suggestions which appear to me to meet the requirements of the situation. As I said at the beginning, I am quite prepared to receive considerable criticism of these; in fact that is one object in putting them forward. For the moment I shall speak only of the university course. The bare matriculation requirement is, in my opinion,

insufficient for entrance to-day upon an engineering course. On the other hand, it is not everyone who can take the Higher School Certificate, as in many cases they would be too old to remain at school to do this. I therefore think that the first essential is for the present educational requirements for matriculation to be modified and a new examination instituted which would cover the ground of the present examination, but in addition would require a standard in chemistry, physics and mathematics, such as could be reached by the normal boy studying for another year after passing his school certificate examination. This examination should only be taken by bona-fide candidates for admission to the university. This would enable the universities to drop a considerable portion of the present first year work and the student would begin his engineering work in the university from the time that he entered. I believe this to be good, not only on academic grounds, but on psychological grounds also. It is undoubtedly rather trying for many students coming to the university from school to find that their first year's work is practically a continuation and, in some cases, a repetition of work they have already done during their school days. With this new matriculation standard a satisfactory three years' course could be arranged by the university in which the student could obtain a thorough knowledge of the fundamental work of engineering science and which would make him fit for the award of an honours degree at the end of the course. The actual details of the syllabus I will leave for the moment, but broadly speaking, the first two years would be common to all students. In the third year I think it is necessary to allow students a choice of subjects. This is done at present in most universities by grouping the candidates as civil, mechanical and electrical engineers, and I see no very good reason for adding to the number of these divisions by creating a fourth branch of aeronautical engineering. For this reason, the engineering student, by the time he has done two years' work, will find that he has a preference for certain subjects and will wish to take these as his main studies. For example, his interests may be in engine work or they may be in structures. He will have done sufficient of each of these subjects in his first two years to allow him to judge as to what really interests him. When he finally enters the aeronautical world he will naturally tend to that branch in which his special abilities are offered most scope; the engine man will go to the engine side and the structures man will go to the constructional side. If, therefore, these subjects, which would be respectively taught in the mechanical and civil departments, were dealt with on broad scientific lines rather than from a technological point of view, the training given would be equally suitable as a preparation for the engineer who will deal with heavy engine or constructional work or for the one who will devote his attention to aeronautical engineering. Do not think that I am suggesting that the courses given everywhere at present meet this requirement; they do not. This is not always the fault of the institutions or of the teachers, but arises from the fact that aeronautics is still so new from the university point of view that the ideas have not yet permeated. I am, however, convinced that this treatment of subjects can be done satisfactorily and ought to be done; as I have already said, this is my conception of the function of the university.

The three years' university work should be sufficient technical and scientific training for the majority of aeronautical engineers as it will be for the majority of civil, mechanical and electrical engineers. The special technique of their jobs must come from experience in the actual practice of their profession. I would not, however, stop the work of a university at this point. There will always be a limited number of students in all branches of engineering who will wish to devote their energies and their attentions to what I may broadly term research, and I think special post-graduate courses should be arranged for such students where they can receive a training of a much more specialised character to fit them for the work they wish to take up. It is not necessary, or even desirable, for all universities to attempt to run such post-graduate courses in all branches of engineering; it is too expensive and there are not enough suitable students

to make it worth doing. Such courses, however, should be available at certain centres and through them would be trained those men who are going to continue the scientific work which alone can lead to real advances in aeronautical engineering. This was, I believe, the idea when the post-graduate School of Aeronautics at the Imperial College was founded. I do not think that it is essential for everyone who wishes to be an aeronautical engineer to go through such a course, but I am certain that such a school can and does produce men who are specially fitted for the scientific development of aeronautics.

These remarks must, I think, from their nature apply particularly to the universities. It is possible that some of the larger technical colleges would be able to adopt the same general lines of engineering education. If they can, well and good, but I think in the case of the smaller institutions scattered throughout the country an attempt to do so would be undesirable. They would not find it possible in most cases to obtain a sufficient number of students with the preliminary education necessary for such a course and should, I think, devote their attention to providing a more technological training such as would fit their students for posts rather different in type from those which the man who had passed through the course I have suggested would be capable of filling. In any branch of engineering there are a number of responsible posts in which a sound but comparatively limited amount of scientific knowledge is required, and the smaller technical colleges would be fulfilling a better purpose by producing men of this type rather than by attempting to compete with the universities.

The present position as regards scholarships is such that any man who has the innate ability to profit by a full university course such as I have outlined can obtain it with very little difficulty or expense. I am afraid, perhaps, I have expressed myself clumsily on this point and I do not wish it to be thought for one moment that I am decrying the work of the technical colleges. That is the last thing I desire to do. I have seen something of the work they do and the men they produce; both are excellent, but at the same time I think that it would be advantageous to students and to institutions if some distinction could be drawn between their functions. There is ample room for both in our educational system, but neither should attempt the work of the other.

A skeleton curriculum for a university course, which would I think prove satisfactory, is given. The divisions of the third year course correspond approximately to the usual mechanical and civil third year. The course in electrical engineering has been omitted as being too specialised for the aeronautical engineer.

The post-graduate course outlined is, I think, substantially that in operation at the Imperial College.

FIRST YEAR COURSE.

Qualification for Entry: Modified Matriculation requirement, equivalent to the present School Certificate examination plus further work in Mathematics, Physics and Chemistry, corresponding to an extra year's study.

Subjects of Study:

Pure Mathematics.	Elements of Applied Mechanics.
Applied Mathematics.	Laboratory work.
Plane and Solid Geometry.	Workshop.

SECOND YEAR COURSE.

Qualification for Entry: Satisfactory work in First Year Course.

Subjects of Study:

Pure Mathematics.	Applied Electricity.
Applied Mathematics.	Theory of Structures.
Strength of Materials.	Fluid Mechanics.
Theory of Machines.	Mechanical Drawing.
Heat Engines.	Laboratory work.

THIRD YEAR COURSE.

Qualification for Entry: Satisfactory work in Second Year Course.

Subjects of Study: One of the following groups:—

(*a*)	(*b*)
Mathematics.	Mathematics.
Strength of Materials and Elasticity.	Strength of Materials and Elasticity.
Thermodynamics and Heat Engines.	Theory of Structures.
Principles of Machine Design.	Fluid Mechanics and Hydraulics.
Fluid Mechanics and Hydraulics.	Principles of Structural Design.
Metallurgy.	Metallurgy.
Laboratory work.	Laboratory work.

POST-GRADUATE COURSE.

Qualification for Entry: Possession of a University Degree or its equivalent.

Subjects of Study:

Mathematics.	Theory and Design of Aircraft Engines.
Aerodynamics.	Meteorology.
Theory and Design of Aircraft Structures.	

Some of these might be optional and laboratory work should play an important part in the course.

Students staying a second year would engage in actual research work under supervision.

VI. Practical Training

I suppose the question of the practical training of the aeronautical engineer is one upon which there will be a certain measure of agreement. We shall all admit that before the young man can call himself an engineer he must go through a course which will familiarise him with the aspects of his job, which can only be learned by contact with works conditions.

Even here, however, there are divergent points of view, and it may be worth while to consider them. In earlier days no one could claim to be an engineer unless he had served an apprenticeship of five years in works; with a recognition of the importance of technical training this period was shortened, and none of the older Institutions now demand more than two or three years.

It seems to me that, in many cases, this training is done in a very uneconomical way from the standpoint of the trainee. In the university the work is carefully arranged so that as much training can be given in the time available as possible, but very often when the young engineer goes into the workshops there is no attempt to organise his work to the best advantage. I think it needs to be remembered that the object of his practical training is to enable him to know how things are made by direct contact with works conditions, rather than to turn him into an expert mechanic himself. It seems to me rather ridiculous to judge a man's engineering ability by his skill as a craftsman. If he has that skill, so much the better, but I do not believe that it is essential. In the same way, every engineer must be able to express his ideas on the drawing board, but it does not follow in the very least that every engineer should be capable of producing a highly finished and beautiful drawing. In many cases, especially in aeronautical work, a restricted period in the workshops and some research training in lieu of the remainder would often be advantageous. Perhaps more than in any other branch of the profession, there are openings in aeronautics for the research man, and, in many cases, a prolonged workshop training may be not only unnecessary but even harmful as a preparation for such work.

Normally, however, it is undoubtedly essential that at least two years should be spent in the workshops, and, since we are assuming that our young engineer is definitely going to be an aeronautical engineer, he will almost certainly go through the works of an aircraft firm—either on the constructional or the engine side. During this two years he should obtain as varied an experience as possible in the different shops, and, in addition, should spend a period in the drawing office. Whether this experience is gained before or after the technical training is largely a matter of individual opinion and choice.

In connection with the practical training of an aeronautical engineer, the question is bound to arise as to the importance of flying. It has been suggested that the ability to pilot an aeroplane should be considered an essential part of the equipment of the aeronautical engineer. This seems to me unnecessary. It is certainly an added qualification, but I am quite certain there are many able aeronautical engineers who would be thoroughly incompetent pilots, and to make a hard-and-fast rule upon this subject would certainly not be in the best interests of the profession.

VII. Summary

I should like now to summarise the views which I have expressed:—

(*a*) The school education of the future aeronautical engineer up to the time when he passes a matriculation examination should be on a broad basis free from vocational training. If possible, the Higher School Certificate examination in scientific subjects should be passed at school to gain exemption from the first year's course at a university.

(*b*) The technical and scientific training may either follow or precede works training. For those who are aiming at design and research appointments this training is best obtained in a university where a normal three years' engineering course would be taken. It is advisable for the men who are able to profit by it to supplement this three years' course by a fourth year devoted to specialised aeronautical engineering science. Those whose aim is to become works engineers and senior draughtsmen would obtain the fundamental technical knowledge necessary from a pass course of three years' duration in a university or a technical college. In many cases a full-time course would be unnecessary, as many of the technical colleges throughout the country provide sufficiently advanced evening classes to enable men who are working during the day either in the shops or in the drawing office to obtain a sufficiently good groundwork of technical knowledge to enable them to qualify for such posts.

(*c*) The practical training should preferably be obtained in aeroplane or engine constructional works. It should be organised so that the young engineer can obtain a working knowledge of all branches in as short a time as possible, bearing in mind that we are training engineers, not craftsmen.

VIII. Conclusion

You have asked me to give my views on the training of the aeronautical engineer, and I have done so in a rather sketchy manner. You will see that in my opinion it takes five or six years from the time of leaving school to reach the stage when the student can consider himself qualified. When he has put in this long period of training, what are his employers going to do for him? There is an unfortunate tendency to think that the young engineer can live on nothing, judging by the salaries that are offered, and I view the situation seriously.

We must, if the industry is to progress, get really well trained men to enter it. The training is long and expensive, and unless the remuneration is

made reasonably attractive the best men will look to other spheres for their careers.

I am sure that it would pay some of our manufacturers handsomely in the long run if they went to some trouble to acquire the right young men just when they are completing their training and pay them a decent salary at once. It would take a little time for them to find their feet, but I am sure the experiment would justify itself very quickly.

It is no use talking about the training of engineers and insisting upon a first-class education if those who go through with such a training do not get a fair chance at the end to prove their ability and receive adequate remuneration while doing so.

Discussion

The President: Not only must Professor Pippard be congratulated on the lecture as it had been prepared, but also on the delightful manner in which he had delivered it. So often the actual reading of a written pamphlet took all the life out of the subject, but on this very difficult theme Professor Pippard had kept his audience extremely interested all the time. As a Member of Parliament, always prepared to speak at length on subjects about which he knew nothing, he would have liked to join in this dispute, but having been dragged up at Harrow and Cambridge, he considered he knew nothing and was therefore out of court. In the circumstances, he would ask Professor Bairstow to open the discussion.

Professor L. Bairstow (Zaharoff Professor of Aeronautics, Imperial College): The paper dealt with a subject which he had discussed in considerable detail on many occasions with the author, and perhaps it was not surprising that he agreed with most of what had been said. Perhaps, however, he might expand what Professor Pippard had said in connection with post-graduate work at the Imperial College. The lecture was entitled "The Training of an Aeronautical Engineer," and although his own department was in the Imperial College, there was no aeronautical "engineering" course—designated as such—and they were just as pleased to have good students from the physics or mathematics departments as they were to have them from the engineering school. The University had recognised that position, and to his own personal discomfort had made him a member of both the Faculties of Science and Engineering. He had to attend both because it did not appear to be known to which subject aeronautics belonged; that, he felt, was a good thing. He agreed with Professor Pippard that, as an aeronautical society, the entrance qualification should be kept very open because the industry required the best trained minds in any of the sciences. If it were possible to choose—and all the other qualifications were the same—there would be the greatest pleasure in training the first-class Honours man. The qualifications, however, were not always the same, and at Imperial College a great deal of pleasure was obtained from training students who had not taken a First Class Honours Degree. Moreover, when there was room to spare, they were willing to take capable students who had not got a Degree. The difference made in their case was that the College was not prepared at the end of the session to grant these students the Diploma of the College.

A serious point to which he wished to refer, continued Professor Bairstow, was the one which Professor Pippard had mentioned last, namely, was a university education worth while? In the case of a boy who had the possibilities of such an education, parents might seriously ask themselves whether the boy would be better off by spending three years in the university or by having the money which would be expended on him in that way handed over to him as a capital asset. If parents were only interested in the boy up to the age of 30, then the best answer would be give him the money, because he would be able to get his own home earlier and secure a better social position. A great deal, of course, depended on the boy, but after 30 the position was not very

pleasant for him under present conditions. For example, the one-time First Class Honours man does not get enough to educate his own children at a university, and it appeared that at the present time the country was to that extent using up its capital. Personally, he did not know what the young people thought about it, and whether they realised that it was possible to fight, but personally he would encourage them not to take the present position too quietly.

Mr. H. E. WIMPERIS (Vice-President of Council; Director of Scientific Research, Air Ministry): Having read through the paper and listened to the very able summary given by the author, he agreed with most of what had been said, and in particular with the view that the education of an aeronautical engineer must always be qualified by the consideration that the community demands that people should be educated for citizenship first, and vocational training afterwards. Therefore he was with Professor Pippard in considering that specialisation should be deferred until quite a late stage, and that the most general form of education should be given first. With regard to the small point mentioned by Professor Pippard as to Oxford University being the only university that called its training "engineering science," it might be borne in mind that the corresponding tripos at Cambridge was called "mechanical sciences," and not "engineering." The paper covered so many aspects of this question that it was only possible to deal with one or two, and the most difficult of them seemed to be whether the workshop experience should come before or after the college training. On the whole, however, he thought it should come after the college training, and the reason why he had come to that conclusion was that he had tried the other method. In quite prehistoric days he was a pupil, or rather a premium apprentice, in a large locomotive works, and went straight there from school. He was supposed to be there for five years, under the tuition of a gentleman called the locomotive superintendent, but with whom he never once exchanged a word throughout the whole time he was there. He did, however, sometimes see this superintendent walking about the works—always with a silk hat on! Going to these works straight from school, with the knowledge that at some stage he would have to go to college, he had realised that it was necessary to keep his book knowledge fairly fresh, and that involved not merely starting work at six o'clock in the morning—as was done in those days—but going to evening classes which went on until ten o'clock at night, and as this happened most nights in the week and there was only a fortnight's holiday during the year, it would not be surprising perhaps when he said that out of a group of men who were in this locomotive works at the same time as himself, those who survived the process could be counted on the fingers of one hand. Nearly all of them fell by the way. It was too much for their health or spirit, or too much for their disposition. In any case, they just gave it up because it was too hard. He was convinced that this method was too hard for the young man straight from school and was expecting too much of him. Moreover, it must be remembered that when a student had been through the college course, he will not require anything like so long a time in engineering works. General experience in the profession had shown that the period in the works is gradually being shortened. At one time it was five years, then it became four years, and later three years, and as head of an organisation which employs a large number of aeronautical engineers, he was coming to the view that the college-trained student could obtain all the works training necessary, from the point of view of this particular organisation, at any rate, in the course of one year. That was a further reason why he was in favour of the engineering works course coming after the university.

The only other point, continued Mr. Wimperis, that he proposed to refer to was that dealing with the subsequent remuneration of trained men—a very important point indeed. This matter could be considered by starting out on the basis that the State was supposed to be the "model employer," and, for present purposes, he would assume this theory to be correct. The State some years

ago appointed a Committee to survey this field in relation not only to aeronautical engineers but other engineers, and the conclusion arrived at by that Committee was that the prospects then held out by the " model employer " were not as " model " as they should be, and the Committee recommended substantial improvements. That report is available for anyone who cares to read it, and personally he regarded the provision made in it as being very good. (He was a member of the Committee.) It provided for exceedingly rapid promotion for the really able people. But State employment was far from being the whole field. Indeed, it was only a very small portion of it. He might also mention that he had quite recently had a conversation with a man who, after spending many years in State service was now in private industry, and his friend's experience had been that, for equal competence and ability, the private employer paid about twice as much as the State. Therefore, concluded Mr. Wimperis, if anybody present connected with private industry as an employer wished to know what should be done in this matter, all he had to do was to read the findings of that report and multiply them by two!

Mr. C. R. FAIREY (Past President) : There were one or two points which appealed to him very strongly. On the question of general education he heartily agreed with the author. He personally was one of those many who spent a great deal of time in physical and mental effort—the physical effort being the most painful—in having drummed into his head some of the immoral exploits of a person called Æneas. Had that time been spent in teaching him any decent language such as French, or the ordinary basis of mathematics, he would have been spared many years slavery at night schools afterwards. Certainly he strongly held the view that we should now start general education on the 1934 basis, and not on the 1634 basis. As to works experience and universities, he had had experience, and from the employer's point of view had developed very definite ideas. The University Engineering Degree had a definite objective and was definitely planned beforehand so that a definite amount of time was spent upon it, and it was now known how much or how little works experience a student needed. The idea that there should be seven years' training in the shops before a person could be called an engineer had been exploded long ago, and sometimes quite a small amount of works experience was sufficient, if it followed upon a good university education. It was absurd to spend three years in a works if six months would serve the same purpose, but if a man was going into the production branch, then he might want seven years in the works.

Coming to the question of employment and the absorption of trained men by the industry, Mr. Fairey emphasised the point that the aeronautical industry is an extremely small one, and very small compared with the ambitions of the rising generation. All the signs seemed to indicate that everybody nowadays wanted to be an aeronautical engineer or, at any rate, wanted to come into the industry. The possibility, therefore, was that the industry would be more than flooded out, despite the expansion of the aeronautical industry which optimistic people always seemed to expect. This applied not only to people with university degrees, but to everyone. Employers in the industry were receiving not scores but literally hundreds of letters every month from ambitious people and anxious parents who wanted to bring their children into the industry, and in many cases they possessed no qualifications whatever. He believed that the aeronautical industry could at least claim to be as wide awake to the importance of this question as any other, and that the prospects for salaries to-day were at least as good as in any other branch of engineering. If the remuneration paid in the industry to engineers, draughtsmen and scientific workers generally was compared with that paid in, say, the shipbuilding industry, he claimed that it compared most favourably. In this connection Mr. Fairey said he also had had a few experiences of other types of employment of an engineering character. Many years ago he was engaged in a municipal electricity works and was expected to be a fully qualified chemist

who was responsible for the condition of the boiler water supply, etc., and it was explained to him the vast responsibilities which this post held, but the salary offered was 17s. 6d. per week. Nevertheless, he had to take the job. On the educative side he had had experience as a lecturer in engineering subjects in evening classes and polytechnics in London many years ago. Although he had to work an hour or two hours a night, and had to travel many miles back again and pay his own expenses, he was rewarded with the munificent sum of 10s. per lecture. Finally he took Professor Bairstow's advice and went on strike. He told the Middlesex Education Committee that he considered his lectures were doing very well and that they were very popular. He most certainly thought they were, and he struck for 15s. per lecture. The result was that he was hurled out into the street and his career as far as educational teaching was concerned came to an end. All this, concluded Mr. Fairey, was only reminiscence and might not be regarded as a useful contribution to the discussion, but he did ask those who criticised the powers of the industry to absorb these aeronautical engineers, to realise that there was a very genuine difficulty. The industry required the highest trained men it could get, and it was agreeable to pay them, but it was only possible to absorb a very few. It was definitely a national problem, and the views he had expressed represented the employers' side in the aeronautical industry.

Prof. R. V. Southwell (Professor of Engineering, Oxford University): Coming from a university which had no school of aeronautics, he was not sure that he was entitled to take part in this discussion; in any event, he had not sufficiently exact knowledge of the customary rates of remuneration to justify him in expressing personal views regarding the conditions of employment in the aeronautical industry. It was, of course, plain that only a few graduates trained in aeronautics could be absorbed by the industry; but he thought Prof. Bairstow's contention was not so much that greater numbers should be absorbed as that higher scales of payment were desirable for those who were absorbed.

One point he wanted to make at the outset: in considering these questions of education, people were perhaps rather too prone to look backwards and consider what alteration in their own training would have made them more successful now. That he considered was not the right standpoint, because it presumed foreknowledge which did not exist at the time; he could not agree with the sentence in Prof. Pippard's paper (the author had not read it that evening) which said: "To-night . . . we are assuming that we can foresee the future of the hypothetical child we are discussing, and know that he will eventually become an aeronautical engineer." If they could be certain, say at the age of 10 years, that a boy was going to be an aeronautical engineer, no doubt it would be possible to devise an optimum course for that boy; but in his experience few boys made up their minds while at school as to what was to be their ultimate career, and it was not until his third year that the average undergraduate had any clear views on the matter. Therefore he thought a scheme of education must not assume certainty regarding the ultimate career of the boy educated, and he personally would go even further than Prof. Pippard in pleading that there should not be undue specialisation at school. He would allow for the late comer to aeronautics or to engineering, and accordingly he would not insist (speaking professionally) on more than three things in the school curriculum—that a boy should be taught (1) how to work; (2) languages, that is a sense of words and how to use them; and (3) mathematics. The last of these subjects was essential to the engineer, and in his view to everyone at the present day, as basis of physics and a particular kind of thinking; the first and second were no less important, and the study of classics could be defended, even on utilitarian grounds, as a means to this end; while surely no scheme of education was complete which left a boy unable both to read and to write English, French and German. The real problem was not so much how to load, as how to lighten the

school programme, and therefore he for one would not insist on more than the three things he had mentioned; but, of course, this view implies that universities must face the necessity of teaching, in a student's first year, not only additional mathematics, but the physics and chemistry which some undergraduates would not have been taught (formally) at school.

Continuing, Prof. Southwell said that he was merely outlining his own ideas of a suitable course, and had no desire to impress it on anyone; he did not see this discussion as an attempt to find an ideal scheme in order to standardise it, and agreed with the remark of Mr. Tizard, " . . . that individuality, which should be a natural growth in universities, needs to be deliberately encouraged in these days of committee rule." He personally would restrict formal teaching in the first university year to mathematics, physics, and (if necessary) elementary chemistry; he did not think that the student need bother about workshops at that stage, and would rather send him to real shops for short periods in vacation. Proceeding in this way the student could cut out mathematics entirely from his second and third years' programmes, because one year's intensive training in mathematics should be sufficient for the formal presentation of the subject; after that mathematics could, and should, be acquired as the practising engineer has to acquire it—in snippets. In these years, too (he agreed with Prof. Pippard), the work should not be too specialised, and concentration on the definite problems of aeronautics should be postponed to a fourth or post-graduate year. The real problem confronting an engineering professor is not how to organise teaching in many subjects (which is relatively easy), but how to leave time for a real grounding in those fundamental principles which are common to all branches of engineering; his aim should be not to turn out a completely trained product (which no university can do), but a student ready and accustomed to learn, and equipped by general training for picking up the specialised knowledge of his chosen profession.

Wing-Commander Cave-Browne-Cave (Professor of Engineering, University of Southampton): In discussing the training of an aeronautical engineer, it was important to realise that training should continue not only up to the end of his formal instruction at a university or elsewhere, but throughout the whole of his subsequent service.

In his formal training should be included principles rather than factual knowledge, because in the learning of principles considerable assistance was necessary, but when these had been grasped, the acquisition of factual knowledge was much more easily done by the individual himself as time went on. This arrangement had the important advantage that the individual kept himself abreast of technical developments which, in aeronautics particularly, changed very rapidly.

The most difficult change which had to be produced in the university course, or any corresponding course of similar institutions, was not so much in the increase of technical knowledge as in the change of state from the much-taught school boy to the engineer capable of getting his own knowledge for himself.

He liked the author's suggestion that a student should take a higher matriculation before entering the university. Matriculation at present was not sufficiently high, because it was so extensively used as a final test for those not going to the university.

Its original meaning was as the first step into a university, but a higher standard for this was now required.

He saw no objection whatever to a student learning at school all the general scientific knowledge he would require, leaving only engineering subjects to be dealt with at the university.

From that stage a three years' course would reach a standard quite sufficient for the great majority of engineers. Aeronautics ought not to be introduced into this course until the last year; even then it would be better for the more advanced

part of the subject to be taken only in an additional year's post-graduate work. For the still more advanced theory required by the research worker a second post-graduate year was probably necessary and well justified.

If a student finished all his general scientific work while at school, leaving his engineering to begin at the university, this point was one at which works experience might possibly be inserted; but he thought it greatly preferable that works experience should follow the university training. It was then possible for the student to begin the process of acquiring factual knowledge for himself, armed with the principles he had already learnt.

This time in works should cover at least two years, and it was quite reasonable that the student should receive very modest pay, because he was benefiting himself so much and his employer so comparatively little.

At the end of this period he was certainly entitled to reasonable pay, but during his first two years he must remember that it was not long ago that firms demanded a very generous premium over a considerable number of years in exchange for this experience and guidance.

As regards practical experience, he agreed with the Author that it was not necessary to make the engineer a really expert draughtsman; or a really expert mechanic; or a really expert pilot; but he must obtain practical experience in all these respects, flying being at least as important as the other two.

It was perhaps not necessary to get much experience as a pilot, but it was essential that the engineer should have long experience as an observer, preferably under experimental conditions.

One of the most important things that an aeronautical engineer ought to ensure was the reliability under working conditions of the apparatus he produced.

Nothing impressed the attributes of reliability upon him more truly than experience in the air under experimental conditions.

He suggested that one of the fields in which the degree man could work with advantage over his brother who had been less fully trained was in experimentation and bringing new devices to a stage of reliability. In this work much depended upon correct methods of experimentation, and it was therefore desirable that the engineer should receive some instruction in how experiments ought to be arranged so as to lead to a definite conclusion.

One of the respects in which the degree man was handicapped as compared with the engineer who went earlier into works was in knowledge of the best methods of handling men and of getting things done.

It was usually contended that this could not be taught by instruction, but the speaker doubted whether a good deal might not be done along these lines by anyone who would take the trouble to collect and sort certain general rules of guidance and conduct.

There was one further great advantage to be derived from extensive work in the air. The man who was known to be constantly flying carried a great deal more weight, not only with the senior members of the firm but also with the men, than did his fellow who worked wholly on the ground.

The engineer thereby became more easily effective, and if he was not effective he was almost useless.

Dr. N. A. V. Piercy (Fellow. East London College): It would not surprise Prof. Pippard to hear that there was much in his paper about university aeronautics with which he completely disagreed. Most of the lecturer's arguments were familiar, and recalled the somewhat Utopian maxims of those who, some fourteen years ago, opposed the introduction of undergraduate aeronautics in London University. He invited them to go back to 1920. If undergraduate aeronautics had failed, this would be suitable; but it had succeeded. To take East London College for example, the students of its aeronautical department now roughly equalled in number those studying civil engineering. The aeronautical students of this college had nearly all gone straight into aeronautics and stayed

there. If numbers so increased as to make this impossible for the moment, they would still be the better all-round engineers for having included some aeronautics in their studies, and would be expected to go out into the world and make aeronautics a bigger thing than it was at present.

The lecturer referred to the " specialist subjects of the aeronautical engineer, for example, aerodynamics." Dr. Piercy heartily disagreed with the suggestion. But he knew the lecturer too well to think that he had meant to make the suggestion, and assumed that the words would be modified in the final draft so as to convey exactly what had been intended. The subject sponsored by London University as aerodynamics was formed, of course, almost entirely of fundamentals not taught in the older subjects of civil and mechanical engineering, although frequently applicable to these older subjects.

The lecturer went on to say, in effect, that there were two alternatives: (1) let the aeronautical engineer's degree contain no aeronautics; or (2) let it be a special degree, presumably in the sense of containing nothing else. There was no reason for this dire choice. It was a well-known fact that students did not all possess brilliance. An effective way of helping at least the less brilliant was to give some rein to their enthusiasm. A student coming to the university to prepare himself for entering aeronautics, whether he conceived his ultimate interests to lie in design, research or administration, was required, in his own interests, to study four or five other engineering subjects besides aeronautics. But he was allowed to spend one-fifth, or a little more, of his time on the work he really liked. This was the alternative that London University sanctioned to a degree with no aeronautics at all. It avoided both the alternatives put forward by Prof. Pippard and steered a middle course.

Everyone would agree with the lecturer that it was chiefly fundamental principles which should be taught to engineers at the university. These occurred in various engineering subjects. But many did not regard as fundamentals suitable for aeronautical engineers: about seven-eighths of hydraulics (*i.e.*, excepting the little matter of pipe flow), highly technical work on steam engines, the technical design of buildings, bridges, bins, etc., or the five subjects full of technical electricity.

It would be a splendid thing to rewrite all the engineering books and syllabuses and to recast all the engineering teaching so as to take into account the wonderful advances of aeronautics. We all hoped this would come about. But it would take time. For example, thirteen years ago London University sanctioned aerodynamics as a half-subject, the other half being hydraulics. The two together were called mechanics of fluids. It was hoped at the time that each half would so encourage the other that soon there would be one subject only—mechanics of fluids—suitable for all engineers. Two years ago, partly at the instigation of the Council of this Society, the position was reviewed. The result was very different from that anticipated thirteen years ago. Aerodynamics was made into a full subject, and hydraulics was put back into its water-tight compartment.

London University had just announced a further step in the same direction: aircraft structure was now sanctioned as a half-subject. Dr. Piercy asked for patience with the syllabus when it appeared; it was delightfully wide and fundamental, but perhaps a little indefinite. A year or two of teaching would show precisely what group of fundamentals to assemble under this heading. In a few more years the matter might come up for review. Would the civil engineers have caught us up in fundamentals by then, or would the Society complain and history repeat itself?

There was just one other point. The speaker had had experience of two types of aeronautical research students—those who had included some aeronautics in their first degrees and those who had not. This experience left him in no doubt that a post-graduate worker desiring a higher degree was severely handi-

capped if he required to spend an appreciable fraction of his meagre allowance of time grasping fundamentals which should have been, but were not, included in his undergraduate training.

Squadron-Leader O. W. CLAPP (Head of De Havilland Technical School): After listening to the author and those who had taken part in the discussion, it seemed to him that the question of the training of aeronautical research workers had been dealt with rather than the training of aeronautical engineers, which was the subject of the paper. He hoped he would not be regarded as too much of a Philistine in mentioning this. The first thing to be done was to define what was meant by an aeronautical engineer. Engineering in the aeronautical world was divided into three categories, viz., design, construction and maintenance, and it was seldom that one man embraced all three categories at once. It was, in his view, necessary to divide the position first into designers, then into production engineers, and then into maintenance or operational engineers. In that way it was possible to cover the field of aeronautical engineering apart from research work, and he was by no means convinced that the training of a research worker was synonymous with that of an engineer. Unless those wishing to enter aeronautical engineering were satisfied to be units of the great army of workers, they would go on with their elementary education until the matriculation standard, or the standard which had been referred to as the Honours Matriculation stage, or possibly follow on to the university. If at the matriculation stage the student wishes to become an aeronautical engineer, it is usual to undergo a premium apprenticeship, a studentship at one of the technical schools run by the larger engineering firms, with a view to absorption into the industry in an executive capacity. This involves at least three years' training, usually until the young man is 21 years of age, during which time he will circulate through the various departments of the works to an organised time schedule, and his ability and progress recorded at each step. He is thus brought into contact in the most familiar way with the running of an industrial concern in all its branches. Starting in a woodwork or fitting section, he progresses from simple work to completed units and then to final assembly. This is followed by experience of design and testing. Where the student shows a special aptitude for any particular branch, he is allowed to specialise. Such schools are run primarily to train young men as executives in the companies concerned. If he followed the matriculation on to the university this would carry the student on until he was, say, 21 years of age, and if he took the post-graduate course it might mean 22 or even later. He would then find that he could obtain only a very meagre wage, and undoubtedly the question would be asked why, with all this scientific training, it was possible to command such a very small salary. The position, however, was that the employer employed men with the idea of making a profit, but at first the work which these men did was not profitable to the employer. When it was, then the employer was quite willing to pay more, and to pay what the man was worth. That, of course, was true not only of engineering, but of all professions and industries.

As far as the operational engineers were concerned, continued Squadron-Leader Clapp, they were scattered all over the world, and it was on their activities that the future of flying depended. They could mar or inspire public confidence by their work. In this he was referring to the large army of ground engineers who maintained aircraft in service. The production engineer required a knowledge of many processes—planning, routing, rate-fixing and progress, together with an inspired ingenuity, not to say a prophetic insight, into future demands. The designer is the essential link between the production engineer and the research worker. He must be a good draughtsman, an intrepid calculator, and must know the ins and outs of every rival design and be capable of producing something at least 12 months ahead of the next man. The training of the designer involved an encyclopædic knowledge of the performance figures, design shapes and patent

specifications and the ability to foresee the finished product in all its manufacturing stages, at the same time keeping a sharp eye on ultimate cost and market potentialities.

He often had people coming to him, continued Squadron-Leader Clapp, saying that the university had taught them nothing which enabled them to earn a living, and it was his duty to try and help them. Finally, he remarked that it was impossible to develop this whole subject in a few words, unless these words be experience, experience—and still more experience.

Reply to Discussion

He was not aware that he had been discussing the training of research workers rather than the training of the aeronautical engineer, as Squadron-Leader Clapp had suggested. Of course, it all depended upon the definition of an aeronautical engineer, and he could hardly accept that given by Squadron-Leader Clapp as being complete. The training suggested in the paper—the ordinary three years' course—would not in itself be sufficient for the research worker, but was a reasonable minimum for any man who wished to be considered a qualified engineer.

He had, of course, expected Dr. Piercy to disagree with him at some points, but he was inclined to think that Dr. Piercy was arguing on a false basis. When he stated, for instance, that it was no use for an aeronautical engineer to learn how to design bridges, he expressed the lecturer's views. The university course should be devoted to principles, not to particular applications; even civil engineering students could not learn to design bridges while at the university, but all students of structures could, and should, be taught basic principles. Dr. Piercy said that he had aeronautical students, but just what was he teaching them? It was necessary to cover the groundwork of structural theory, for example, before any attempt could be made to associate it particularly with aeronautics. Hydraulics was also mentioned, but a great deal of the old subject of hydraulics was useless and was just the sort of thing it was necessary to get away from. In the lecturer's view, it was as important for civil and mechanical engineers to know something of aerodynamics in the broad sense as it was for aeronautical engineers. Fluid mechanics, embracing aerodynamics and hydraulics, should be taught to all students.

Prof. Southwell and himself seemed to be fairly well agreed, and he was interested in what Prof. Southwell had said concerning physics and mathematics at Oxford. In most universities a great deal of time was devoted to these subjects in the second and third years, and if that could be avoided it would leave a great deal more time for engineering subjects in those years. The lecturer certainly thought that the necessary formal mathematics, in many cases, could be done in the first year.

Prof. Pippard agreed with Mr. Fairey that the pay in the aeronautical industry was as good as that in any other branch of the profession of engineering. He apologised to Mr. Wimperis for forgetting the mechanical science tripos at Cambridge, but would ask whether the school was known as a school of science or a school of engineering.

Mr. Wimperis said that colloquially it was engineering.

Resumed Discussion

The discussion on Professor A. J. Sutton Pippard's paper on "The Training of an Aeronautical Engineer," which was presented at the meeting on October 18, 1934, was resumed at a Special Meeting held in the Library of the Society on Tuesday, November 20, 1934.

The President (Lieut.-Col. J. T. Moore-Brabazon): He expressed regret that at the previous meeting there was not sufficient time to complete the discussion on Professor Pippard's paper. It was the great desire of the Council that the younger members should take part in these discussions, and therefore this Special

Meeting had been called to give them that opportunity. In calling upon Major Barlow to open the discussion, the President said he would ask Major Barlow subsequently to take the chair, as he himself had to leave in order to be back in the House of Commons.

Major BARLOW (Chief Engineer, Fairey Aviation Co., Ltd.) : He was glad of the opportunity of saying a few words to express his view of the situation, as he saw it as a member of the aircraft industry. He did not propose to discuss the training of engineers for the Air Ministry, or for the technical branch at Farnborough, Felixstowe, or Martlesham, nor to touch on anything dealing with air transport, but to deal with the training of young engineers for the design and construction of aircraft and engines.

In his lecture Professor Pippard had outlined what he thought was an ideal training, but he would like to add to it in certain respects following the experience he had had many years ago in training for an electrical engineer. He was certain that the men who followed their university or technical college training by either one year in the shops and one year in the drawing office—or, alternatively, one year in research and one year in the shops—certainly went ahead of the men who had a limited training. It really meant at least two years were required after their theoretical training to help to put that part on a practical basis. His own training was on these lines, but he was convinced the situation as it was thirty years ago was the same to-day. One year abroad was an important addition to an engineer student's training. Personally he was not able to do that, but he was of the opinion an aeronautical student's worth was increased at the outset by some 20 per cent. if this could be achieved. That year abroad should be spent in France, Germany, or the U.S.A., and this brought a further point to his mind—the question of a foreign language. He stressed the necessity of a modern foreign language such as French or German as an important assistance to any student who wished to make his way in aeronautical engineering.

Finally, on the general question of training, Major Barlow pointed out that the Associate Fellowship examination of the Society had been brought up to date and now did all that was necessary as regards examination for theoretical training, and it could be said definitely that there was no Associate Fellow of the Society who had passed that examination who was out of work at the present time. If there was one, then he would give him a job to-morrow morning.

Commenting upon the young fellows that came into the industry from universities or technical colleges, Major Barlow said the majority of them have no idea whatever of mechanical drawing, and many of them could hardly read a blueprint. Surely there was something wrong there, because in the old days the one thing in which a very complete training was given was mechanical draughtsmanship. That, however, was quite overlooked to-day, and it was a common thing to find men coming along with excellent credentials with regard to mathematics, physics, aerodynamics and other matters but who were absolutely at a loss in many practical points such as mechanical drawing. They did not seem to have had any training in processing or manufacture of materials, for example. The universities seemed to leave that entirely out. The same comments could be made with regard to the union of theory and practice. The universities trained these men on the theoretical side, but completely forgot the practical application of that training.

Turning to the capacity of the industry for absorbing trained men, Major Barlow said that in the " Aeroplane " a fortnight ago there was a comprehensive list of firms which, when analysed, indicated that there were twenty firms making aircraft in England, thirty firms associated with the manufacture of materials, forty were concerned with service, and seven with aerodrome equipment. There was no doubt that the manufacturers of aircraft material, and aircraft service companies, were only too pleased to have the services of men with actual knowledge of aircraft, and this was an outlet for engineers which should not be overlooked.

If the number of men engaged in the aircraft manufacturing firms was analysed it would be found that they absorbed from 1,500 to 1,600 technical draughtsmen, and probably 70 to 80 jig and tool draughtsmen. In addition, so far as he could judge, there were not at the outside more than 120 executive men in the industry; that is, men who would be earning £1,000 a year or over. That was a fact which should be borne in mind, although the future possibilities of employment in the industry must not be based on the present position of the industry, but what might be expected of it in the future. The average wage or salary of the 1,500 to 1,600 men to whom he had referred would be £5 to £8 a week, with senior draughtsmen earning from £400 to £600 a year. They were, of course, approximate figures and represented the total employed at the present time. It might be asked by some students present how was the staff recruited to fill up vacancies. The position was that, in addition to trained men from the universities and colleges, there were workmen apprentices who were learning the trade and who attended evening classes. These young fellows made excellent draughtsmen because the technical schools really did teach draughtsmanship and, of course, were in the fortunate position of being engaged in the daytime in actual shops. This, therefore, was the stock which the firms in the aeronautical industry drew upon. Then there were some coming out from the R.A.F. who made very good men and formed a further supply.

Another aspect of training was that to-day students seemed to shirk responsibility. Out of 120 of his present staff, he doubted whether there were more than half-a-dozen who were prepared to accept responsibility, and the reason for that he failed to find. That was not what occurred in 1904, and although it might sound futile to enter into reminiscences on such an occasion, the fact was that at works like those of Messrs. Siemens, everybody was keen to accept responsibility, sought it, and worked for it, and this was the real key to promotion. Finally, Major Barlow pointed out to those entering the industry that it is a young one and it would be found that the heads of departments in nearly every case were not over 50 years of age. All these people hoped to have at least another 10 years of active life, and the fact to be borne in mind, therefore, was that it would probably be another 10 years before very many of the senior posts became vacant. In these circumstances, students must be prepared to come in on the ground floor and work hard and put their backs into the job; if they did that there was no reason why the young engineer who entered the aeronautical industry and stuck to it should not, by the time he was 30 years of age, be getting £400 or £500 a year. Beyond that, it was entirely up to the man himself.

Stanley H. Evans (Associate Fellow): It is perhaps characteristic of the Royal Aeronautical Society that they should choose a distinguished aeronautical scientist to present a paper on the training of aeronautical engineers, and then call upon other eminent scientists to rub it in. From the designer's viewpoint, he was glad to have this further opportunity of disagreeing with Prof. Pippard's ideas *in toto*.

At the outset of his remarks, he wanted to congratulate the lecturer, however, upon his courage in being thrown to the lions that evening. Speaking as a lion who has had his tail twisted pretty severely during the past six years in the States, he was feeling more than usually hungry at the moment. He was sure it was not Prof. Pippard's fault if the Society were unable to distinguish between the education of an aeronautical research physicist and the technical or professional training of an aeronautical engineer.

First of all he wanted to cross swords with the lecturer upon his definition of the meaning of the term "engineer," as understood by those who make their living designing and producing aircraft. Surely the derivation of the word itself from the Latin "ingenium," as "one skilled (or ingenious) in the arts of invention," is a reliable signpost along the path of the embryo engineer? But could there be any surer way of killing the art of invention than the typical

university curriculum outlined in the paper and all too familiar to those who have been encouraged to plod through its weary boredom in their misguided youth? He supposed it was rank heresy to say it before such a scientific society as this, but he had often thought that most universities are temperamentally unfitted to teach engineering as practised in the industrial world of to-day. Curiously enough, Prof. Pippard rather naïvely admits this indictment, since he is honest enough to suggest that their exclusive function should be the teaching of engineering *science*, which is a bird of quite another feather.

It is a hoary argument whether aeronautical engineering is a science at all, rather than an art practised with the latest weapons provided by a technological age; a conference of imagination, calculation and artistic flair, as much as a problem in Newtonian mechanics or the Calculus. This art has to be practised at the bench and the drawing-board, rather than in the cloistered atmosphere of a schoolroom—superbly aloof from the industrial scene of trial and travail. Say what one will, the very heart of this problem of training an aeronautical engineer (or any other kind for that matter) is that *something has got to be designed and actually built by the student himself*. In his opinion—from personal experience as a student and instructor—the universities invariably over-stress the importance of mathematics as a mental conjuring trick, rather than as an engineering tool to be used and placed in the rack as and when required. Conversely, they invariably underrate the vital importance to the industry of mechanical drawing and design, and the production of decent shop drawing for ordinary blueprint reproduction.

One of the most common fruits of this fetish-worship of mathematics is the type of student who becomes adroit in the mechanics of mathematical manipulation without ever realising the true significance of an equation from the design standpoint. By this he meant they have been taught by a maths. professor (seldom by an engineer) to obtain every formula from first principles, entirely forgetting the most important term which is for ever cropping up in design practice. The term he had in mind was capital " J," for " judgment."

He could marshal together dozens of everyday illustrations of this one point, but a typical one will suffice to drive home what he meant. Consider any column formula one liked and the overriding influence of the fixity coefficient upon the allowable stress value for design purposes. He had watched many students manipulate the mathematical chessboard and derive their old friend Euler. But what then? The end-fixing conditions remain a question of capital " J," based upon experience or static-test results, so the tortuous turning of the mathematical mill is merely another form of mental cruelty leading them back to the need of factual knowledge, rather than the " cramming " of first principles.

He would like to direct attention to one particular paragraph of the paper. The author remarks that: " Whether he will use the particular work in his later professional practice is of no concern to the teacher and of no particular importance. The training and the fundamental knowledge is what matters, and not the application of it. That will come later." Later in the paper the author says: " When he has put in this long period of training (five or six years), what are his employers going to do for him? There is an unfortunate tendency to think that the young engineer can live on nothing, judging by the salaries that are offered, and I view the situation seriously . . ." etc. In plain language, the employer is now asked to pay for the deficiencies inculcated by the university system—where pure thinking is preferred to creative endeavour, and active doing is beyond scorn. He could assure Professor Pippard that he was not alone in viewing the situation seriously. It would be an altruistic age indeed if every employer could be persuaded to take this philanthropic—and mediæval—view of his function in industry!

The skeleton curriculum outlined in the paper is typical of the university outlook. The marked absence of mechanical drawing, machine design and

workshop practice from actual specimen examples is to be expected in the academic world. Moreover, the English universities have not yet discovered that manufacturing economics (*i.e.*, the principles of industrial engineering as applied to production problems) is equally worthy of study and research. Many American universities include this subject in their engineering curricula, and he was firmly of the opinion that the student needs to have some idea of industrial organisation and management before entering the industry. The curious thing that struck him about Professor Pippard's curriculum is that most of the theory and so-called fundamental principles could be obtained as well—in fact, probably better by an ambitious student—by diligent study of a well-written correspondence course. This may sound like outrageous heresy again (it is!), but a famous American professor once remarked that " most lectures ought to have gone out of fashion with the invention of printing." He thought there was a germ of truth in the statement.

His view, which he ventured to think was a common one within the ranks of the industry, is that this type of curriculum is based almost entirely upon the needs of a very small minority of students intending to become research physicists, rather than design, construction, or operating engineers. Whenever he was asked by young fellows wishing to enter the industry, he told them to go and have a look at such training centres as the De Havilland Technical School, or the College of Aeronautical Engineering. He really believed that these schools and their type are getting closer to the real heart of the engineering problem. Surely the central problem in our case is to produce better aircraft? Everything else, *including research*, is merely incidental.

Furthermore, he believed he was not alone in feeling that their research workers were being misled into a scientific *cul de sac*. In fact, he had been agreeably surprised at the growing volume of criticism on this score since his return from the States. He felt, in all sincerity, that the Society would be doing a service to the profession in sifting the evidence. It is notorious that many of our most capable design staffs prefer to base their technical work upon the results of the American N.A.C.A., rather than the A.R.C. He had no hesitation in suggesting that they needed a new orientation in research for the aircraft industry if they hoped to hold their export markets. And he spoke with some inside knowledge of conditions in the United States.

Mr. H. S. Ellis (Student): He quite agreed that the present university curriculum does not give a man judgment for the work he would have to do when he came into the industry later on. Personally, he felt that if a student took a B.Sc. straight from school he should be prepared, when entering the industry, either to pay to be trained or at any rate he should not expect a high salary, because it could not be expected that a manufacturer could pay him when he could not do what the manufacturer wanted. It was only when the student could actually do work which earned money for the manufacturer that he could be expected to be paid on a proper basis. The university did not give the judgment which was necessary for this. It gave a certain training which in later years would perhaps give the student a broader outlook and develop his mind. That was the main function of the university degree, and if a student desired to become an engineer rapidly and to earn a living as soon as possible after his leaving school, his best plan was to go to one of the technical schools, which would give him an inside knowledge and enable him to earn money immediately. If, later on, he desired to become more of a scientist he must adjust his training accordingly. In aviation, science was more essential than in any other branch of engineering. Other branches might have proceeded, in the past, without an immediate application of science, because it had been possible to build up by experience. That, however, was not possible in aviation because we did not know sufficient about aeronautics to build up in that way, and therefore the application of science now, as at the very commencement, was essential.

It was not until the Wright Brothers brought science to bear on their experiments that real flight was attained. Previously experimenters had been trying to build up on the basis of experience, but those methods were not successful, and it was not until science was brought to bear that success was achieved. That state of affairs, in his view, would apply in even greater measure in the future, and therefore if an aeronautical engineer desired to be both an engineer and a scientist he should, in his opinion, be an engineer first and then have some special training in order to obtain the necessary scientific knowledge. There should be some sort of link between the scientist and mathematician, and the practical engineer; but, at the moment, there was very little in the way of such a link. There was the mathematician and the engineer and a gap between them. University-trained men with practical experience were well qualified for filling such a gap and doing research work in the industry, but they must have that combination of training and experience if they were to be of any real value.

Squadron-Leader CLAPP (De Havilland Technical School): With reference to the Chairman's comments on R.A.F.-trained personnel, he said he had had 20 years' experience of the R.A.F., and after 14 years' experience of training ground personnel he certainly agreed that some of these fellows were quite useful. The school at Halton, for example, had about 50 Graduated masters teaching mathematics, aerodynamics, mechanics, drawing, etc., and the student or pupil who left that school with the rank of leading aircraftsman, or corporal, was in every way equivalent to the class of pupil who passed through the technical colleges. Certainly, in his opinion, such men were not inferior to men who came from these other places; moreover, the R.A.F. training was rather expensive, because there was generally a three years' course for the practical and theoretical training. With regard to the De Havilland School, of which he had the honour to be Principal, there they trained young men of the public school type having matriculation or its equivalent, and put them through a two or three years' course. The two years' course was designed for those people who had had some previous engineering experience, whilst the three years' course was designed for those who started from zero. During the daytime there was vocational training in the actual manufacture of aircraft parts, and during the past 2½ years the students at the school had built eight standard aircraft as made by the firm. Of course, the students had available, if necessary, the jigs, press tools, etc., belonging to the company, but generally he insisted on these things being done by hand in order to give them the necessary experience. Anybody, of course, could braze a job if he had gas and air laid on; but out in the desert, for example, or when one was, say, stranded "in the blue," gas and air were not available, so that these men should be taught to do brazing with a blow-lamp. It might be crude, but these crude methods produced the skilled craftsman in the end. The students also passed a certain amount of time in the actual workshops of the company, and a number of them every year were able to qualify for the Associate Fellowship examination of the Society. This year there had been introduced the Associate Membership examination, and he understood that it was intended that the Associate Fellowship examination should apply only to pure research workers, whilst the Associate Membership examination was intended to apply to technical workers. At any rate, the students would continue to take the examination, whatever the intention was, and they had been promised by Sir John Siddeley that those persons who held these qualifications of Associate Fellowship or Associate Membership, would be considered for positions in the industry before those who had not, and that was a point of view to which he personally fully subscribed. Evening classes were held on five evenings per week for the necessary theoretical subjects.

Continuing, Squadron-Leader Clapp said that during the past year, under the supervision of Mr. Langley, the students at the De Havilland School had designed a machine known as TK1, which was more or less a standard type

of biplane, and it would probably be remembered by some that this machine obtained fifth place in the King's Cup Race. The students designed the whole machine throughout and built it, and it was flown by an ex-student. At the present moment they were engaged on a second machine, TK2, which was a monoplane, and equally good results were hoped for. In this way the students were combining the design side with the practical side. All this experimental work, moreover, was in addition to the work which the students did in the actual workshops of the company in connection with the construction of standard types of machine. Generally speaking, continued Squadron-Leader Clapp, he held the view that it is possible to train the brain as much by the hand as the eye, and it was fairly safe to say that a man who was skilled with his hands could thus train his brain. Therefore, it was believed that the actual carrying out of the practical side of the work, from start to finish, from the design right through to the manufactured article, is what is wanted in the training of an aeronautical engineer. The whole of the company's resources were open to these young fellows, and they circulated—although not necessarily on a time basis, but on a knowledge basis—through the various shops. As soon as a student had got to know what was considered sufficient in one department, he was passed on to the next. The students were sent into each department with a list of 30 or 40 things which they were specially to look out for. Suppose, for example, a batch of heat-treated high-speed steel parts had gone through just before the student got into that particular department, the system was such that he would pick this up later on, and in that way he did not miss anything. After a certain time in each department the student was examined by the instructors of the school, and if he was considered satisfactory he went to the next department. If not, he remained in the particular department for a further period, and, indeed, it might be necessary to tell a particular student at the end of his two years' course that he had not made the progress he should have done and that it was advisable to extend the course. This was not because there was a need for students; indeed, as a matter of fact, he had a prospective list of students waiting. The school was not advertised in any way, but people seemed to find out about it and he was booking up students for years and years ahead. At the present time the school was limited to the number it could take for two reasons: (1) the saturation of the shops, and (2) the state of the industry.

The CHAIRMAN: Would the speaker suggest a course, such as he had so clearly outlined, as additional to the degree or university course?

Squadron-Leader CLAPP: Mr. Ellis, who had just spoken, had had two years at the De Havilland School and had gone to the East London College under Professor Piercy for further instruction, and undoubtedly Mr. Ellis was a student who was capable and should do well as a research worker.

The CHAIRMAN: That bore out what he had tried to stress in his opening remarks.

Squadron-Leader CLAPP: He agreed.

Mr. ROBERTS (Principal, Chelsea College of Aeronautical Engineering): The only way he could really express his views on this subject, in which he was so immensely interested, was by describing what he had done in organising the College of Aeronautical Engineering for training men coming into the industry to earn a living. He realised from the start that the job for the university was to give a man a good education, and not necessarily to provide a vocational training. He very strongly held the view that for a man to be of value to the industry he must be trained in the things with which he had to earn his living. The university training should follow a certain amount of practical training, and the practical training should be on a very wide basis. The principle adopted in his college was to eliminate first of all those students who were not likely to be successful in the industry, if after three months the conclusion was arrived at, on the reports of the instructors, that particular students would be unsuitable

for the work. Students often came to the college saying they wanted to take up flying, but it often became obvious that they would be no good at engineering, and although they were very disappointed, it was inevitable that they should be told the facts. The college provided a three years' training on different types of aircraft and engines, together with general engineering experience. It was possible to obtain experience in the shops at Chelsea with 15 different types of aircraft engines, and the students had to strip, rebuild, and test these engines and get them back again to flying standards without doing any actual flying. Again, they had to reach a certain standard of mechanical work in welding, fitting, machine shop, woodwork, foundry work, etc., because a boy could not become an aero engineer without having a basis of mechanical engineering. Having done this, he went on to the aircraft section at Brooklands, where he was engaged in woodwork, metalwork, rigging and construction of aircraft, etc. During the course he was trained on the theoretical side for the Royal Aeronautical Society's Associate Membership or Associate Fellowship examinations appropriate to his capabilities. At the same time, said Mr. Roberts, he realised there was a limit to what any college could do. Every boy coming into the industry in this way should have a certain amount of experience under commercial conditions and with certain of the firms in the industry. With that end in view, the College of Aeronautical Engineering now had arrangements with a large number of firms whereby boys were taken in and given practical training under works conditions.

Continuing, Mr. Roberts said he would divide the industry under three heads: (1) the manufacturing side; (2) the maintenance side, and (3) the aerodrome and operating side, and a boy who was obviously fitted for one of these branches went to a particular firm and obtained six or nine months' experience under practical conditions and received definite instruction in the work. At the end of that time, which would be after two and three-quarters or three years, that boy had to be helped on for another three years in the industry, and the college had found that all the students obtained fairly good pay when they left—a fact which he attributed to their training having been partly in the works with a firm engaged in the particular branch the student desired to be conversant with. One thing which he felt was against the university method of education was that it put the theoretical side first, and a young fellow coming from the university, therefore, had to have a considerable period of practical experience. One of the first things that had been said to him when he started the College of Aeronautical Engineering was as to how many he was going to train, having regard to the fact that the industry was a small one. As a matter of fact, he had been very careful to keep the standard of students at a very high level, whereas the universities were taking on many students and were training a number of people on the more highly technical side out of all proportion to the ability of the industry to absorb them. On the other hand, he felt that if the universities were to make their training a little less on the highly technical side and substituted a certain amount of practical experience, this question of the smallness of wage which firms were offering to men from the universities would not be quite so much in evidence. At any rate, he had not found the complaint so serious with men going from the College of Aeronautical Engineering, and he attributed that to the fact that they were trained in the manner in which they had to earn their living. To-day, with competition as it was, we could not afford to attach too much importance to the purely theoretical side. He was well aware of the fact that people went to universities with the object of being trained so as to obtain better paid positions, but he felt that if the number of students accepted for the universities was limited, and more practical experience was given to them, the value of a university training would be very different from what it was to-day.

The CHAIRMAN: Arising out of Mr. Roberts's remarks, it appeared to him that there might be a way out if the university put off specialising in aeronautics

until at least the third or fourth year. With regard to the payment of men coming into the industry, he said that in the case of his own company, the starting pay for a man with a degree in engineering was £3 a week. If the man was prepared to start at that and to come in and work hard, there was no reason why he should not be self-supporting. It was obvious that he could not paint the town " red " on such a salary or run a motor-car, but he could keep himself, and it should be remembered that twenty years ago when the electrical industry was in its infancy, and was, as a matter of fact, very much in the same position as aviation was to-day as regards young engineers, many people came into the industry on the basic pay of 30s. per week. As a matter of fact, hundreds of electrical engineering students lived on that for several years and put their backs into the work in order to make better positions for themselves. The young student must remember that he could not start off with enough money to get married on and run a house and a motor car. He must go through several years of hard graft.

Wing-Commander CAVE-BROWNE-CAVE (Professor of Engineering, University of Southampton): His experience as a practical engineer was so much longer than as a professor, that he naturally looked at the problem chiefly from the engineering point of view.

There was a great deal to be said for taking practical engineering training before the degree work. It ensured that only those candidates who could derive full advantage from the more advanced theoretical work devoted to it, the three or four years which would otherwise be available for acquiring further practical experience and perhaps earning a considerable amount of money.

In his experience, the greatest difficulty in taking the degree course late lay in the risk that students would forget the mathematics and physics which they knew when they left school and would require for the degree course.

If it were possible to arrange, as no doubt the De Havilland School did, that all students while getting their practical experience did keep their mathematics and science actively useful, then the degree should certainly follow this practical experience and be taken only by those who proved really suitable for it.

The distinction between engineers and research workers had been emphasised. He, personally, thought that a future research worker would benefit greatly from a preliminary practical training coming before the more scientific degree work, and the still more advanced theory, involved in his later work. No one could say that it would damage the genius of the researcher; it would certainly improve his knowledge of practical conditions and increase the probability that his research would be fertile.

At Southampton he was responsible for all grades of engineering training—the evening classes, the degree course for London University, and the intermediate part-time system. He saw clearly how desirable it would be that students should start at the practical end of this ladder, if it were possible for the cleverest ones still to proceed to the degree course. There was, however, the difficulty that students who had not matriculated at school were faced with that examination, which proved very difficult if taken some years later.

He did not agree that the present university course was likely to suppress inventiveness. His own experience was that degree students were singularly lacking in inventiveness, and probably more so than those of twenty years ago.

They also lacked ability to work by themselves with general guidance.

Both these defects were, perhaps, due to the care and detailed attention which had been given during their school training.

Mr. M. LANGLEY (Member of Council): He wished to start by calling attention to what he considered to be a rather serious confusion in the paper, where the author classified the aeronautical engineer into various groups. The final group was Design or Research engineers, as if those two were the same thing.

From his own experience, however, he felt that they were very definitely not the same thing. They should be quite separate categories.

The university method of training engineers, continued Mr. Langley, had existed for many years and was very much older than the aircraft industry. Therefore, one would expect to find in the aircraft industry a high proportion of university-trained engineers, particularly as the industry was one which had no traditional or rule-of-thumb methods behind it. Was that, however, the position in the aircraft industry to-day? It was in this connection that he came to a point dealt with in the paper where the author said: "For certain of the grades, which I have for convenience included in the title of aeronautical engineer, it is perhaps possible to dispense with a full-time course at such an institution, but unless this is obtained, the chances of rising to a position of even minor importance are very limited except in very rare cases of exceptional ability." Pick out what are considered to be the outstanding aeroplanes of the past few years, whether they be military, civil or commercial. Then ask if those machines were designed by men who were university trained. In his view it would be found that the majority of these machines were not designed by university-trained men. But he rather hesitated to bring in the names to a discussion of this sort which was being reported.

Professor PIPPARD: I think we can quite well have the names here. They can be taken out for publication purposes if necessary. I think we might have a perfectly free discussion.

Mr. LANGLEY, continuing, named three outstanding machines, one military, one commercial, and one racing, produced by firms, the chief designers of which were not trained in a university.

The CHAIRMAN: In one case the designer is a member of the Institution of Civil Engineers—that examination is equivalent to being a university-trained engineer.

Mr. LANGLEY: That was exactly what he was trying to stress. An engineer trained for the examination of the Institution of Civil Engineers was, in his view, a much more useful man than the university-trained type of engineer, because the Institution of Civil Engineers' examination was very definitely practical. Moreover, "equivalent to" is not the same as "identical with." Therefore, the conclusion which Professor Pippard had drawn was not based on scientific evidence. He was inclined to say it was based rather on bias. One of the greatest weaknesses in the university method of training engineers was that it was based entirely on examination results. These results were liable to indicate little more than the student's state of health on a particular day, whether he was well or ill, and whether his nerves were in a state of repose or otherwise. Too often the principal law of mathematics studied was that governing the periodicity of certain stock questions. He suggested that we should get away from the examination bogey which went right back to matriculation—a test taken at an age when the student was fit neither psychologically nor physiologically to stand the strain of an examination without taking a "permanent set."

Dealing with the De Havilland School, Mr. Langley said a boy having a good educational background was put into the technical school of the aircraft factory, where he was given some months' training in the use of tools. Then he had a period in the workshops of the firm learning how to make things, how to assemble them, and gaining some knowledge of the service troubles which cropped up. This latter, as a matter of fact, was a very important part of design. The designer must base a great deal of his work on the reports of the service or maintenance engineers. The student was given sufficient time in each department to gain some knowledge of every important process in the manufacture of aeroplanes. The parts he himself made were to be used on aeroplanes that were actually going to fly, and they must be up to A.I.D. standard. Therefore, the student was given a sense of responsibility from the very start. Running

parallel with this workshop training were the evening classes in aerodynamics, mathematics, mechanics, ground engineering, and materials, including metallurgy. At these evening classes the lecturers were members of the firm's own designing staff, and therefore were in touch with the actual problems which the future designer would have to tackle.

Professor PIPPARD: You say that the teachers are in touch with the present problems that the designer has to tackle?

Mr. LANGLEY: Yes.

Professor PIPPARD: That is a distinction, and a very important one from my point of view.

Mr. LANGLEY: In view of that remark, he could see the line which Professor Pippard was taking. He gathered that Professor Pippard was suggesting that the scientist was discovering things which the engineer was going to use in future years, but there was also the point of view that the scientist was investigating things which the engineer had already discovered, and was merely finding an explanation for them—an explanation in which certain symbols were fitted to facts already known.

Continuing his remarks as to the course at the De Havilland School, Mr. Langley said that when the student showed promise, having gone through the stages already indicated, he passed to the design department. Here he began with simple detail drawings and worked up to the design of main components and their stressing. He also did performance calculations and applied the knowledge gained from the evening lectures. At the end of 18 months in the drawing office he was doing the same work as the senior draughtsman, and the value of this training was seen in the fact that the machine T.K.1 was completely designed and built by the students in the school. Although Sqd.-Leader Clapp had given him some credit in this connection, it was a fact, said Mr. Langley, that he himself had made neither drawings nor calculations at any stage of the work. The students had done the whole thing. He contended that the methods adopted at the De Havilland School in making the students design machines which were going to fly induced a sense of responsibility from the start. The student, having finished his course, could go straight into a drawing office without finding any change of atmosphere. The university-trained man had to adapt himself to a very different atmosphere and different surroundings—a process which took time. The De Havilland Company now recruited the junior members of the drawing office staff from the technical school, and these fellows were quickly falling into responsible jobs and proving very satisfactory. There was no unemployment problem amongst them, and many had passed the Associate Membership or Associate Fellowship examination of the Society. He did not suggest that this type of training was suitable for the research worker, but, at the same time, he felt that even the research worker would be better for a period in the more realistic atmosphere of the factory and aerodrome. Indeed, it would be good for the university lecturer to spend one year out of four in an aircraft factory, studying the differences between research and design work.

The CHAIRMAN: Referring to the point previously made by Mr. Langley as to the number of chief designers being university-trained men, he pointed out that there is no such thing as a sole designer in aircraft firms at the present time.

Mr. LANGLEY: Professor Pippard had said that one could not get a position even of *minor* importance in the industry without a university training. His point was that the chief designers he had referred to had reached positions of primary importance without that particular training.

The CHAIRMAN: Out of the Directorate of five on the Fairey Aviation Co., three are university trained—quite a large proportion.

Professor PIPPARD: I think it is the general case.

The CHAIRMAN: He thought they would find it is about 50/50 generally.

Mr. LANGLEY: He merely wished to make the point that a man can get into a position of more than minor importance without a university education. Associate Membership of the Institution of Civil Engineers or of the Institution of Aeronautical Engineers does not imply a university training, and is more valuable than a degree to the engineer.

The 1934 edition of " Who's Who in British Aviation " shows that less than one-quarter of Chief Designers of our aircraft constructing firms have university degrees. Of course they may all have university-trained men on their staffs in more junior positions.

Mr. H. SIMS-WHITE (Associate): He had found Professor Pippard's paper very interesting and agreed with many of the views which he has expressed, but, so far as the main topic is concerned, he was in entire disagreement. The syllabus which he has put forward as suitable for a university degree course to be taken by those who wish to enter the aeronautical profession is not, in his opinion, at all satisfactory. It is possible to take a degree in civil, mechanical and electrical engineering, and he could not see any reason why persons wishing to follow an aeronautical career should not be able to take a degree in that particular branch. Surely such subjects as aerodynamics, the theory and design of aircraft structures, and the theory and design of aircraft engines should not be considered as the subjects *only* of a post-graduate course? They are the very subjects which give the aeronautical engineer his designation and which distinguish him from a civil, a mechanical, or an electrical engineer; they are the subjects which should, most decidedly, be dealt with in the final year in place of general machine and structural design—the study of which constitutes a waste of time so far as the aeronautical student is concerned. He would, in fact, be in favour of a general extension of the degree course to four years, the subject of aerodynamics being introduced in the third year, and the fourth year being devoted to the completion of aerodynamics and to the subject of the theory and design of aircraft structures, or the theory and design of aero engines.

He also noticed that Professor Pippard suggests that the entrance examination should be of a modified matriculation standard equivalent to the present school certificate examination, plus further work in mathematics, physics and chemistry, corresponding to an extra year's study, and yet he includes in the first year portion of his suggested course such subjects as plane and solid geometry and the elements of applied mechanics. Surely these would have already been covered in the entrance examination? He thought that a better scheme would be to devote the first year to more advanced mathematics, applied electricity, strength of materials, theory of structures and mechanical drawing, the latter to be completed in the second year.

Based on the above remarks, and with other slight modifications, his suggested syllabus, in detail, is as follows:—

Entrance Examination.

Modified matriculation examination as outlined by Professor Pippard.

First Year.

Pure and Applied Mathematics.
Applied Electricity.
Strength of Materials.
Theory of Structures.
Mechanical Drawing.

Second Year.

Pure and Applied Mathematics.
Strength of Materials.
Theory of Machines.
Thermodynamics and Heat Engines.
Theory of Structures.
Fluid Mechanics.
Mechanical Drawing.
Laboratory Work.

Third Year.

(*a*)	(*b*)
Mathematics.	Mathematics.
Strength of Materials.	Strength of Materials.
Heat Engines.	Theory of Structures.
Metallurgy.	Metallurgy.
Fluid Mechanics and Hydraulics.	Fluid Mechanics and Hydraulics.
Aerodynamics.	Aerodynamics.
Laboratory Work.	Laboratory Work.

Fourth Year.

Aerodynamics (continued),
Theory and Design of Aircraft Structures;
or
Theory and Design of Aero Engines,
Laboratory Work.

With regard to practical work, his experience has been that far too little importance is attached to drawing office training. Such training is, in his opinion, very desirable for all, irrespective of whether an engineering or a research career is contemplated. One usually finds that in whatever capacity one is engaged, the ability to—at least—read a drawing is a great advantage, if not a necessity. The latter is, however, more often the case.

He held the view that practical work should follow theoretical training, and that the former should consist of at least eighteen months in the workshop and eighteen months in the drawing office.

Mr. R. C. B. Hendy (Associate Member): A student attending this lecture must have gone away feeling thoroughly disheartened, thinking that he could not possibly get a job in the aircraft industry unless his parents could afford to enable him to take a degree at a university.

Now this is very far from being the case.

The speaker has always considered that one of the advantages of the industry is that one can get into it, and get on in it, without being a very great expense to one's parents. Before one begins to talk about the training of aeronautical engineers, one must consider the various kinds of engineers that the manufacturer wants, and is eager to employ. They are very roughly as follows: Fitters, sheet metal workers, machinists, woodworkers, erectors, inspectors, planning and costing specialists, works managers, stress and performance calculators, draughtsmen, designers, and test pilots.

Now these grades are employed at salaries of between two hundred and two thousand pounds a year. They all require a specialised training, but only a very few of them require a university training. There is no doubt that a university training is of very great value, and the man with a degree is a fortunate individual. Several of the greatest designers and aircraft manufacturers to-day have not had a university training. They obtained their technical training at night schools while working as apprentices in factories during the day.

One is told that there is a very great risk of over-crowding in the industry. In spite of this, it is impossible to get enough really good engineers in the grades that I have mentioned. Manufacturers at times are at their wits' end to get men. There are plenty to be had of a kind, but really good ones do not exist—and they are not being trained. A supply of good fitters is as essential as good designers and research workers.

The universities are training men by the hundred for the highly-paid jobs when there are no jobs for them. On the other hand, the men that are wanted cannot be got in sufficient numbers.

Unless something is done to remedy this state of affairs there will be a great shortage of the type of men that are so necessary in a healthy aircraft industry.

Mr. J. L. B. Jones, B.Sc. (Student) : One rightly expected that Professor Pippard's treatment of a controversial subject would hardly be such as to arouse the wrath of a University Senate for the second time in a short period. It remains for those not so well versed in the virtue and value of restraint to criticise with ease; and, certainly with less ease, to contribute something of a more constructive nature.

The university department of engineering is chiefly concerned with the accumulation of an increasing fund of knowledge from the treatment of subjects of industrial interest in the light of purely scientific principles—" in that calm atmosphere beloved of the scientist and appropriate to the university or research establishment. In his inmost heart the scientist is more interested in reasons than results." (R.Ae.S. Journal, Vol. 38, p. 754.) In view of this statement, made by such an eminent authority, one may suffer misgivings as to the ability of the universities to produce a man—useful to industry in any other capacity than that of research worker.

At present the employer who accepts a university-trained engineer who has had no previous works training, engages to increase his overhead expenses for a period of two years—perhaps more; at the best it is a speculation, and one on which he may have no return. It is impossible to blame the employer or the engineering graduate, entering on another long period of unremunerative labour, for the materialistic attitude in which they view the situation. One admits that training in a works itself is essential; but cannot the university course be so arranged that, on entering industry, one's effort is, in some direction, immediately productive?

The solution seems to be not so much in any rearrangement of lecture courses as in a complete revision of laboratory, drawing office and workshop courses. These should be conducted in aeronautics and under conditions as completely similar to those prevailing in industry as may possibly be attained. At the same time, a portion of the long vacation should be utilised for compulsory works training—the employer might be more helpful in this direction.

Also, there is need for the introduction of a new lecture course—Economics of Engineering. Everyone should be trained to consider any engineering problem first in its relation to the factors on which the structure of industry is grounded and maintained. Secondly a single language course, chosen at will from perhaps three, might be made compulsory.

It may be pleaded that the available time is already too short. Under the present system this is so. It would, therefore, be helpful in this direction if overlapping between school and university training was entirely eliminated. The man who is prepared in mathematics for Oxford and Cambridge Entrance Scholarships, or for the Joint Board Higher Certificate, as a candidate for pass with distinction —often a prospective engineer—would complete the mathematics papers in Engineering Finals (London), with time to spare, whilst still at school. Yet if he elects to read engineering at a modern university, he is required to take the first year engineering course. A system of regulations permitting waste of time may be deplored—compelling waste it cannot too strongly be condemned.

Finally, much as one may regret it, the increasing tendency towards specialisation in industry itself seems to demand a greater degree of specialisation in our academic training if we are adequately, and immediately, to perform what is required of us. It would be instructive to know how far the extensive practice of this may be reckoned successful in America.

Mr. G. D. Duguid (Chelsea School of Aeronautical Engineering) : Professor Pippard has stated that the matriculation is a hurdle which must be taken in his stride by the student, and to indicate a basic standard of education this appears to be the accepted test at the moment.

He did not agree, however, that the successful student should then progress to the Higher School Certificate, but the last year at school should be spent in really educating the boy—not in pushing him through an examination syllabus. The chief result of this examination fetish is usually the very bad habit, from an engineering standpoint, of memorising a lot of notes and data without really understanding what they mean. A further bad effect is lack of adaptability when faced by new problems or difficulties. He considered the last year at school should be devoted to the development of clear, precise, and logical thinking, to the inculcation of a reasoning and enquiring type of mind, an ability to marshal facts, to weigh the pros and cons of any problem, dismiss redundant matter, and from any facts available deduce a reasoned and logical conclusion. Too many students learn only exactly what they are told, and seem unable to correlate classroom instruction with practical application; due, he thought, to an attitude of mind which looks on every problem as a pencil and paper one. To overcome this tendency, the last year at school should combine a laboratory course of chemistry and physics, and particularly of applied mechanics.

A general knowledge course would be of great benefit, covering general scientific and physical phenomena. A good working knowledge of a modern language (conversational if possible) is a great asset, a knowledge of the best English literature should be included, and a course of English composition and self-expression is vital, including the correct use of words, as many engineers may be called upon to make lucid and precise reports.

The power of clear, logical and orderly thought in approaching a problem should be innate in the engineer, and he considered this mental training to be of the utmost importance if the technical knowledge gained subsequently is to be used to the greatest advantage. They were endeavouring to introduce a preliminary mental training of this description into their probationary term at Chelsea, but they have not yet quite decided on what form it should take.

Before commenting on the somewhat controversial topic of the best technical and practical training for the engineer, he would prefer to divide up the large body of men who may be classed under the very wide term " engineer " into about four distinct grades, which differ slightly from those adopted by the author of this paper.

In the first grade he would eliminate men who, although attached to the engineering industry, cannot be classed as engineers proper, men engaged in pure research or investigation into branches of chemistry and physics; for example, he would prefer to class metallurgy under the heading of applied chemistry rather than engineering. In this class also one can include the inventor and experimenter, who may, or may not, be engineers. There is, however, a radical difference between scientific experiment and engineering practice; in the former case the tendency is to work everything out from the ideal standpoint, possibly by methods which are too refined for the workshop.

He considered that the job of the research and experimental *engineer* is to arrive at a very fair approximation of the results worked out in the laboratory, and evolve methods which can be used under practical engineering conditions. He thought that a scientific education is essential for this class of engineer, and yet he is most definitely an engineer, rather than a scientist, although he should be capable of carrying out scientific research himself, or in any case be able to evolve suitable methods for carrying out research.

The third, and probably most numerous class is the one which he had in mind when speaking of " engineer." This is the class of men who take the results of invention, research, experiment, or mere accidental discovery, and put them into concrete and usable form, by designing and fabricating the necessary machines or structures.

Closely allied to this class are the repair, maintenance and operating engineers, which again form a large body. Fourthly there is the sales engineer, whom

he thought would gradually displace the mere salesman, who may, perhaps have little knowledge of his product.

Regarding the training and qualifications of these four grades, there cannot be any doubt that, for the first two grades, a university education is absolutely essential. In the case of the pure research man he agreed with the author that he is probably better without workshop experience, but in the case of the research engineer, he thought workshop experience *was* essential.

Turning now to the large class which he had grouped as " engineers," what qualifications and training are necessary?

He is convinced that it is impossible to " make " an engineer. Any aspirant to the profession of engineering must be possessed first of all of an inborn or innate " something " which is rather difficult to define. It may, perhaps, be defined as a mechanical intuition; a " flair " for engineering; a machine sense; a mechanical resourcefulness or aptitude; or what the psychologists call a fundamental "g." Without this gift, in however limited a form, he considered that the chances of turning out a reasonably successful engineer are practically nil.

He was prepared to admit that this type can be trained in routine work, he can be made into an efficient machine-minder or operator, but will never become an engineer in the true sense of the word. With this fundamental something, even in a somewhat limited form, the rôle of the teacher is to foster and develop it, harness it, link it up with orderly and scientific thinking, powers of observation, and a sense of proportion, with, of course, the essential technical and practical knowledge which are the " machine-tools " of the engineer. He was, therefore, in agreement with the author that all students should have at least twelve months in the shops before entering a university. During this period the prospective student will be able to satisfy himself that he possesses the necessary aptitude and keenness, otherwise he will fall by the wayside, and probably decide that his bent lies elsewhere than in engineering; also he will not be called upon to attempt to design machines or structures which he has never seen, and of whose practical functions he has no experience.

This was the attitude taken up by the Principal at the Chelsea School when he insisted on a probationary term at the college to discover whether a student is reasonably likely to succeed in engineering work. It has been their unfortunate lot to turn down students who have been extremely interested in engineering, who have been extremely keen to learn, who have worked and studied very hard, but who have simply not had the necessary fundamental aptitude to profit by engineering training.

But, if a man had this particular mechanical bent, he agreed with the author that even though they forcibly fed him on an indigestible diet of differential equations, and so on, he would probably survive, and still be a good engineer. If he did not possess this aptitude he would fail, in spite of all one could do for him.

In choosing suitable students for Wakefield Scholarships at the college, papers were set in general knowledge, mathematics and mechanics, chemistry and physics. They also asked the Institute of Industrial Psychology to help them in carrying out a series of mechanical aptitude tests. It is rather interesting to note that the students who obtained good marks in these aptitude tests were reported on extremely favourably by their instructors within two weeks of joining the college, and the instructors in question had not the slightest idea that they were scholarship students, or that they had undergone any such tests.

Regarding the ideal curriculum, he did not feel prepared to discuss this at any length, because he felt that the particular curriculum is so much a matter of personal opinion and experience. At Chelsea their own endeavour is to combine all the best features of the works system with that of the technical college.

They try to advance theory and practice hand in hand, as it were, and with the great advantage that both are under one controlling head.

They are thus able to correlate, and synchronise, theoretical study with practical application. To take an obvious case, a student in the machine shop comes up against the quick and " short-cut " methods of the shop in cutting a screw at the same time as he is obtaining lectures on gearing, velocity ratios and simple compound trains, etc., so that the two are inseparably linked in his mind, giving him an intelligent appreciation of his work.

He would like to state, in case of any misapprehension, that he was a university graduate himself. He was advised to take up engineering work because he happened to be fairly good at mathematics, but he considered that the mathematical and engineering mind may have little in common—the brilliant mathematician may be a failure as an engineer. On the other hand, to anyone possessing a true engineering instinct, a university training is undoubtedly of very great advantage, provided that the necessary intellectual capacity is available to profit by it, but an exclusive mathematical training may lead one to approach all problems from a mathematical standpoint, and there are many problems in engineering which cannot be solved in this way.

He considered that shop experience is most essential; the engineer must design with ease of production in his mind, just as much as the general functioning of the design, and he must be fully conversant with the difficulties which may arise in the shops. Not only must the engineer know his own part of the work, and that of industries closely allied, but he must also be able to appreciate the results of previous research, and the most likely effects of research in the future.

Dealing with the fourth class of sales engineer which he mentioned, fairly obviously commercial knowledge is necessary, and the saleability of the product may at times assume a rather important aspect.

Employment seems to be a matter of supply and demand, also governed by the fact that in some cases it may be difficult to fit the young engineer into an existing organisation, or a vacancy may not be available in the particular branch which his experience enables him to hold.

Dr. Piercy (East London College): He agreed that in the matter of draughtsmanship the university student of to-day is not to be compared with the university student of twenty years ago, and indeed was worse equipped than the student of many technical colleges. As a matter of fact, the policy at some universities, as he understood it, was to give still less attention to proficiency in accurate drawing; a general view being that the three years at the university were too occupied to produce fine draughtsmen. He also agreed that some reference might well be introduced to metallurgy and heat problems, and clearly this could be done in an undergraduate course. He also held the view, which was shared by some of his past students now occupying responsible positions in industry, that more mathematics should be taught—and in such a way that students could really use this tool in practical problems. The time was rapidly passing when an engineer could hope to succeed professionally, whether in aeronautics or elsewhere, without any useful mathematics worth mentioning, and as for the charge that had been made that a university education killed ingenuity, he thought a little more attention to this subject would certainly provide any correction necessary. But every professional engineer knew that he must have some command of many subjects to go far: for instance of physics, chemistry, workshop processes, costing, to name a few Certainly the universities did not reckon on turning out engineers at the age of 20-22; he would be doing well who became an engineer at the age of 35-40. Dr. Piercy liked the view of the Institution of Civil Engineers, which body would not accept a degree as full exemption from their Associate Membership examination; they thought that, even at the age of 25, a young engineer should have progressed farther and should pass a more practical examination in addition. They also required works training by then,

and were more stringent on mathematics than the university was. He was glad there had been little tendency to discuss university versus other forms of education. The form of education followed by a student was often a matter of expediency, and there was room for several forms which should help one another.

Mr. D. R. Pye (Assistant Director of Scientific Research, Air Ministry. Member of Council) (*communicated*) : The lecturer referred to the variety of types of qualification which may be included among those of an aeronautical engineer, but he confined himself mainly to discussing the full three- or four-year courses of university training. He (the writer) suggests that any general discussion by this Society should embrace all fields of engine work for which Associate Fellowship of the Society is regarded as a necessary, or at any rate desirable, qualification. As qualities which are necessary in all fields of engineering, he would like to suggest:—

(1) That an engineer must have a *quantitative* mind, by which he meant that he must be trained so as to be able to size-up a situation in a quantitative manner, in terms of whatever the variables may be.

(2) His knowledge need not be comprehensive, but he must have developed the faculty to *get up* any particular piece of scientific or technical work of which a knowledge may become essential in his field of practical engineering.

(3) He must be able to express himself, when writing a report, in clear and precise language.

This last ability is vitally important, and much too often it is found that men, highly qualified scientifically, are deplorably bad at expressing themselves precisely. In this connection he was inclined to quarrel with the lecturer for his gibe at a classical education. No serious defender of a classical education ever claimed that it was capable of " making a boy intelligent." On the other hand, he believed personally that it does lead, better than any other form of school education, to clear, ordered thinking and writing, for the reason that the forms of the sentences in Latin, for example, are so different from those in their own language that it is impossible for a boy to do a piece of translation in either direction correctly without first having got perfectly clear as to the meaning to be conveyed, before attempting to set this down in translation. Even German does not achieve this training to the same extent, and French scarcely at all.

The problem which the Society is discussing, however, turns mainly upon how far scientific and technical work should go in order to provide the degrees of training requisite for each class of engineer under the general headings (1) and (2) given above. It was suggested by one speaker that the lecturer had discussed only the training of research workers, and that for executive engineers a three years' university training was superfluous, if not a disqualification. He recently had an opportunity of a round-table discussion with all the technical heads of a well-known aero engine manufacturing firm, and ascertained that, without exception, they considered scientific training up to and including B.Sc. standard was valuable, but they regarded it as equally important that before spending his three or four years at a university course, a boy should get about a year of practical experience in works. This entirely coincides with his own view, and he would add that this year can with great advantage be spent in works abroad. The break with school work can be minimised if arrangements are made for time off from the works and some evening class study. In this and other discussions with executive engineers on the design and constructional side, he had found a general concensus of opinion that a thorough training in science and mathematics, even to the exclusion of definitely engineering subjects, is regarded as being of the first importance. Very little of what is learnt in a university engineering course will be of any direct value during subsequent experience, because it is impossible for a university training in such matters as

design and materials to be other than out of date, to some degree, and a man must expect to have to learn what he needs to know, and how to use this, after he has come into contact with the practical problems of a manufacturing concern.

While he was convinced that for the man of good ability who hopes to go far in the designing and executive staff of a constructing firm, a university course (preceded, if possible, by a year in works) is desirable, ten years in close touch with the technical leaders of the industry has only confirmed the suspicion he had formed during eleven years of university teaching, that a large proportion of the men who go for three or four years of university study would be spending their time more profitably in works, while taking the minimum of theoretical study demanded by the examinations for Associateship of the professional Institutions such as the Institution of Civil Engineers and the Royal Aeronautical Society. If these men get to the front at all, they will do so by influence or by force of character, not by what they have learnt at a university. Men go to universities for very diverse reasons. From the point of view simply of vocational training as engineers, he felt a good deal of sympathy with those who criticise the products of the universities, and suggest that the latter produce ineffective engineers; but to his mind the critics are very wide of the mark in suggesting that university courses are, therefore, valueless except for the research worker, and he believed that the majority of the leaders of industry would take this view. The fact is that many young men go to universities who are either too stupid or too idle to profit by their time there. The universities provide good facilities for producing the best kind of engineer from the right kind of material, but there is a large class of whom the atmosphere and experience of engineering works is much more likely to produce something useful; possibly something of the very highest value.

Mr. H. G. Fozard (Chelsea College of Aeronautical Engineering) (*communicated*): Having had approximately twenty years in the aeronautical industry, it appears to the writer that, during the discussion, the question of the supply of engineers to occupy positions of responsibility, such as works superintendents, works managers, inspectors (both Air Ministry and with the firms employed upon the manufacture of aircraft, and this also would include the many firms employed upon the production of raw material, etc., which were enumerated by Major Barlow), and finally for positions of responsibility and administration in the operation of civil aircraft, has been neglected. He would, therefore, like to state that although the various forms of training that have been mentioned meet the requirements for certain branches of the industry, he felt that the remarks by Mr. Roberts, the Principal of the College of Aeronautical Engineering, could be supplemented by some detail.

It may definitely be assumed that all the students taking up a course of aeronautical engineering do not desire to be designers or research engineers, and therefore there must be some alternative which will enable them to obtain first hand knowledge of the very numerous materials, the Air Ministry regulations, and operations involved in the manufacture and operation of aircraft and engines.

It would therefore appear that the line of action to be taken would differ considerably from that of the university course indicated by Professor Pippard, and whilst agreeing that such a course is very good groundwork, he was not at all sure that a further twelve months in a factory or drawing office would enable a student to obtain the necessary knowledge required by a works manager, an Air Ministry Inspector, or an operating engineer.

To supply this comprehensive training, it is absolutely necessary that the student should attend a college or technical school which lays itself out definitely to provide the necessary training. The College of Aeronautical Engineering does fulfil these requirements. In making this statement he was speaking from an experience which covers the manufacture, inspection, operation of aircraft,

and considerable experience in the drawing office in this country and the United States and Canada.

The question now arises: how is this training to be carried out?

As stated by Mr. Duguid, it is very essential that a probationary term be given to eliminate the students that will never make engineers. This is incorporated in the College of Aeronautical Engineering Syllabus, and the student's first term is spent in the fitting and engine shops. At the end of that period he is assessed in the fitting shop on a practical fitting job—soldering and brazing. In the engine shop he is assessed by the instructor on his practical work on engines and on an examination in the theory of engines.

It will be noted that this supplements, somewhat, Mr. Langley's remarks to the effect that a report from an instructor who has had a student under personal observation is far better than an examination. With this he agreed, but one must be conventional and also cope with the human element in the instructor. He therefore considered that an instructor's assessment, supplemented by the examination results, which are in most cases consistent, are considered desirable.

Bearing in mind that a student may possibly become an operating engineer, his first period of training at the Chelsea College is primarily on the overhaul of engines. During this period he attends lectures on mathematics and heat engines, and the maintenance of the engines upon which he is engaged in overhauling.

At the end of each term he does a practical examination, and also examinations on mathematics and theory of heat engines. If he obtains a 50 per cent. pass, based upon the instructor's assessment and his practical examination, he passes to another shop, which may be the woodwork, welding, foundry, electrical or drawing office.

Taking the welding shop for example, he receives a period of six weeks instruction on oxyacetylene welding, and receives lectures on the material normally used for welding in aircraft structures and fittings, the heat treatment that follows, and a knowledge of the checks on the various materials and the gas used to ensure serviceable work.

At the end of six weeks, he does a practical job of welding and is assessed by the instructor, based upon the student's initiative, ability and progress during the term, and a practical examination test which is assessed by a member of an outside firm.

If again successful, the student passes to the woodwork shop, where he learns the use of tools and is employed on the making of scarf joints, ribs, etc., from actual workshop drawings, and also receives lectures on timber, its characteristics and defects, etc.

Before leaving the woodwork shop he has an examination job covering a period of six hours, in which he has to carry out a job of work from a drawing. It will be noted that in this department he is now working from drawings, and the commencement of that training which will finally enable him to readily understand and interpret drawings used in aircraft manufacture, etc.

He may now pass to the drawing office, the electrical shop, or foundry, and the above procedure is carried out. During this period a close check is kept on the progress of the student to ensure that a good standard of efficiency is being attained, based upon the standard set by the Air Ministry requirements in connection with aeronautical work.

Included in the foregoing periods the student receives lectures on metallurgy, that is, the fundamentals of heat treatment of steels, etc., and composition of alloy—both ferrous and non-ferrous—and testing and strength of materials.

Finally, at the end of a period of 15 months, if the student has passed all the subjects he has taken, and has attained a satisfactory standard, he is transferred to Brooklands.

On arrival at Brooklands, his first job consists of making jigs for the production of ribs to drawings. In a very short time he is qualified to undertake repairs to small components such as rudders, elevators and fins. He also has lectures on fabric, testing and identification of same, use of the correct thread, correct seams and dope schemes—all very essential for the knowledge of a works executive, inspector or operating engineer, and draughtsman.

He also receives lectures on timber to enable him to judge the quality, protective coverings, varnish, etc., and such operations as glueing.

At the end of six weeks he has another practical test, and also an examination paper on the theory relating to the work done. If the results of the examination are satisfactory, he then passes to advanced woodwork, which consists of laying out of jigs for building up fuselages, wings, and other components used in aircraft, and also the repair of components and methods of repair as laid down by aircraft manufacturers and the Air Ministry. This is of considerable importance because it has a direct bearing upon the examination for the B ground engineer's licence, which the student will probably take after some post-college experience. It also has a definite bearing on the ground engineer's licence for the A category, which the student will obtain at a subsequent date.

A more advanced examination is again taken at the completion of a further six weeks, and the student then passes to the metalwork shop.

In the metalwork shop he learns to make metal fittings, components, tanks, riveting, heat treatment, and repairs to various types of metal aircraft, *i.e.*, welded, tubular and strip steel construction, and particulars of the B.E.S.A. and D.T.D. specifications involved. He also receives lectures upon protective coverings used in connection with metal aircraft, such as anodic treatment and chromium and cadmium plating, enamelling, etc., in conformity with AP.1208. Students are also given lectures and detailed descriptions of the modern methods of production of aircraft fittings and metal components in general use at aircraft works, and also the design of press tools and jigs. The heat treatment of alloy steels and aluminium alloys is also included.

On the completion of three months in the metalwork shop, he has a six-hour practical job to do and two examination papers on theory.

During this period he has also been attending lectures on the theory of flight, wireless and draughtsmanship.

If he has now attained a good reliable standard he then passes to the erection and maintenance of aircraft, which normally covers a period of three months, during which time he receives instruction on the erection and maintenance of a number of types of aircraft which include, of course, all the accessories.

At the end of this period he is then given a practical job on the erection, installation and maintenance of the aircraft, and has a written examination covering the work he has done.

Lectures on aerodrome management, etc., are included in this period.

His training is now completed so far as Brooklands is concerned, providing he passes the following examinations, namely, an oral examination, a six-hour practical job on metal work, and a six-hour practical job on woodwork, in each case working from actual workshop drawings, and his assessment is definitely based upon an employable value. The oral examination is similar to the A and B licence examinations at the Air Ministry and is assessed by three senior members of the college, and if the student passes satisfactorily he is then transferred to Chelsea for three weeks' revision on the complete overhaul of light engines and the testing of same. This also includes a period in the test house and a short period on compression-type combustion engines.

The student then has a further oral examination, which is equivalent to the Air Ministry examination for a C licence, and if he is up to the required standard he is transferred to one of a series of aircraft manufacturing and operating companies which are co-operating with the college to enable a student to obtain

a final six months' experience, which has the effect of smoothing out or tapering off the college complex, and preparing him for serious work, and also has the effect of enabling the students to obtain good experience under actual commercial conditions in accordance with mutual arrangements between the college and the companies.

If a student is interested in the works side of the industry he will probably select a company engaged in the manufacture of aircraft; and if the operation side, he will select a company engaged upon operation. He then sits for the Air Ministry ground engineers' licences A and C, and must be successful before a diploma is granted.

He has now reached the stage when he possesses a definite employable value, ranging from £2 10s. to £5 per week. These figures are based upon the salaries obtained by ex-students, who have had no difficulty in retaining their jobs in several branches of the industry.

In the course of time these students will find that branch of the industry which best suits their requirements, but in the early stages of their earning career it is not essential that they be too particular about the branch of aeronautical work they undertake.

He might state that, during the period of training at the college, students are coached for the Society's examinations for the Associate Fellowship and Associate Membership, and a number of students have been particularly successful.

He thought it would be agreed that the above training is a very comprehensive one for a student who does not desire to take up the research side of the industry, which, of course, offers a very limited number of openings. It does, however, definitely offer a good training for the branches that have the largest number of vacancies, and it must be agreed that the primary object of taking up a course of training is to attain a standard of efficiency that will ensure the ability to obtain a salary consistent with one's reasonable requirements.

Students who desire to take up the drawing office side of aeronautical engineering attend a special advanced class of draughtsmanship, which enables them to produce complete working drawings for the shops, together with an introduction to the fundamental principles of stressing as applied in the industry.

As stated by Major Barlow, the majority of the higher or administrative positions in the industry are held by persons engaged at salaries from £300 to £600 a year, and the above training meets the requirements necessary to qualify for these positions.

There is no doubt, however, that a percentage of the better students will qualify for the higher salary, but this, he thought it would be agreed, depended largely upon the opportunity.

He thought, therefore, it would be agreed that whilst the training outlined in the author's papers complies with a demand, yet there is room for a modified training to meet the definite requirements of the industry calling for qualifications regarding subjects which are not included in the university course, and it would, he was sure, be difficult for the post-graduate to obtain this training in a works or drawing office, for unfortunately there is little scope in a works engaged upon production to obtain the necessary training, unless, of course, there is a definite organisation for this purpose.

Reply to Resumed Discussion

He found it extremely difficult to give anything like a full reply to the mass of suggestions, criticisms and questions which had been thrown at him. At the same time, he did not wish the meeting to close without dealing with some of the more important ones.

Mr. Evans had referred to him as a scientist: he was an engineer by training and experience, and it was as an engineer that he gave his views on a training which his experience made him believe would produce men such as the industry

needed. The training he had suggested was not intended for scientists, but for engineers.

A SPEAKER: In " Aeronautical Engineering " this paper had been given the title of " Training for Aeronautical Science."

Professor PIPPARD: The title was altered without his consent, and he knew nothing about it until the paper in question appeared. He objected to that change, and had he known it earlier it would not have occurred.

He agreed with the Chairman that the graduate was not getting experience in manufacturing processes or real practical metallurgy. He was, however, getting a training in drawing, and he could not agree with the Chairman on that particular point. The question as to students not being prepared to take responsibility had been raised on other occasions. It was not suggested that the average man coming from the university could be put into a position of trust and responsibility immediately: he could not. The man had to get his works training first, and he agreed with what had been said that some of the schemes referred to that evening, *e.g.*, the Chelsea School, the De Havilland, and others, offered admirable training for a certain type of student; indeed, the descriptions that had been given of the courses at these schools illustrated the point in the paper when it was suggested that the technical schools in many cases would be doing better service if they stuck to their proper job. The schools mentioned were properly doing the work of technical centres, and were just what technical schools should be. Men attending them were not being trained primarily for any particular examination; the training, it is true, was such as to enable them to take the examination of the Royal Aeronautical Society, but he was certain that precisely the same training would be given if no such examination existed.

Mr. LANGLEY: Exactly. They were training men to do a job.

Professor PIPPARD: He agreed that such schools were training men quite admirably for certain posts, and the curriculum from that point of view was good. He was sure that there were openings in the industry for men who had had such a training. There was, he thought, no better definition of an engineer than that mentioned by Mr. Evans, namely, " one skilled in the art of invention," but in that connection he heartily disagreed with the view that the faculty for invention was killed by university training. A man who had an inventive mind had something which probably could not be killed. It was a spark of genius, and a university education would help to utilise this genius to the best advantage. If university education killed the inventive faculty, he would agree that it would constitute the most damning indictment of such education, but he was convinced that this was not the case. Mr. Evans also suggested that the university did not teach engineering as a practical subject. This was true, and he was in agreement with that outlook. It was not the duty of the university to train an engineer in the technique of his profession, but to give the student such a training in engineering science as would serve as a basis for subsequent practical training, and professional work.

On the question of salary, he said that when he pleaded for a decent salary he was well aware that employers could not be expected to give a youngster straight from the university a salary which would enable him to get married and run a motor car. He did suggest, however, that it was worth while for the employer to pay a commencing salary of, say, £3 per week, such as the Chairman had mentioned, in order to get the pick of the men coming from the universities. The employer in the end would find that he would be repaid that £3 per week many times over.

There was, perhaps, some justification for the comment that the universities were training too many men. He personally thought so, but, on the other hand, in spite of the slump we had gone through, the fact remained that practically all of his last year's students were employed. Indeed, the trouble had been to

find men to fill some of the vacancies. There did not appear to be a large number of men leaving the universities who were stranded at the end of three months.

Dealing with the criticism that university training does not give judgment, it could not be expected to give judgment on practical engineering points. It could, however, train a man's mind so that when he had acquired the technique of the particular job upon which he was engaged, any inherent ability he possessed would be properly utilised.

It had been suggested that there was no link between the mathematician and the engineer, but that was just one of the things that an engineering training should give. He agreed with those people who despised the mere trickery of mathematics as a training for engineers, and he also regarded mathematics as a tool for their use.

Professor Pippard pointed out that progress in aviation depended largely on the work of the scientist. Certain particular aeroplanes had been mentioned as evidence of the superior ability of men without university training. It was only fair to ask how much of the success of these machines was due to the work of the R.A.E. and the N.P.L.

Mr. EVANS: But one cannot read their reports.

Professor PIPPARD: If that were the case, then it was the strongest argument yet produced for a university training for aeronautical engineers.

The CHAIRMAN: No.

Mr. EVANS: The point there, is that they used the N.A.C.A. reports and not the British.

The CHAIRMAN: He thought that was general throughout the industry.

Professor PIPPARD: In reply to Mr. Langley's comments, he ought perhaps to have differentiated between the designer and the research worker in the paper, but he had in mind that their training would be very similar; at any rate that they must both be men who had received the best possible training. A man with a flair for design with such training would naturally gravitate towards the design side, just as a man with a flair for research would try to make it his life work. He had certainly not meant to suggest that the two were the same, and was aware of the distinction pointed out by Mr. Langley.

It might possibly be instructive to compile a list of designers in this country to discover who were university trained men and who were not, but whatever the result of such a census at the moment, he believed there would be an increasing tendency for such posts to be filled by men with university training.

He did not think any university teacher would disagree with Mr. Langley in what he had said regarding examinations, but was it possible to replace them by some other test?

Mr. EVANS: No examination will make a good designing engineer.

Professor PIPPARD: He agreed, and added that no examination could be expected to *make* any kind of a man. An examination was not held for that purpose.

Mr. LANGLEY: At the De Havilland School they relied very little on examination results. They relied much more on reports made by the individual instructors who watched the progress of the students, and very often watched them when they did not know they were being watched. In that way it was more easily possible to weed them out than by examination. This method " caught them bending " so to speak.

Professor PIPPARD: Something of this sort was done in the case of the Diploma at the Imperial College, which was granted as the result of a year's post-graduate work. There was no examination, and reliance was placed upon the reports of the teachers.

A SPEAKER: With reference to the question of a substitute for an examination said that a friend of his who applied for a job in pre-war days as a draughtsman

in a big bridge-building firm in America, was told that if he could design a bridge he would get the job. He did so and got the job, and it seemed to him a practical way of solving the examination problem.

Professor PIPPARD: It might be from the one aspect of design.

A SPEAKER: The firm in question told the applicant where the library was and left him to get on with the work.

Professor PIPPARD: He had tried that method as an experiment on a class. He gave them the option of an examination on ordinary lines or an examination in which they were allowed to use any notes or books they pleased, and they chose the latter.

A SPEAKER: Were you satisfied?

Professor PIPPARD: The examination order was precisely that in which he would have arranged the men. The student who knew his subject and did not have to make use of the books got through all right, but the student who did not know his subject spent the greater part of his time looking through the books to find solutions to the problems set. However, this question was a very difficult one, and every teacher, whether in a university or a technical school, would agree that it was unsatisfactory from many points of view. It had been suggested that a year in the works would do teachers a great deal of good, and undoubtedly many of them would be glad to do it, because most university teachers were engineers at heart, even if they were devoting their lives to teaching engineering science. Equally, however, it would not hurt most designers to spend some part of their time in the university!

Mr. LANGLEY: Many of our designers would like the holiday which is implied in that!

Professor PIPPARD: If a change of occupation were a holiday, the time spent in a university might be regarded as such.

Continuing, with regard to special degrees in aeronautics, mentioned by Mr. Sims-White, he said that had been discussed in the paper, and he had given his views there why he did not think them necessary. It had been suggested that plane and solid geometry and mechanics should be done at the matriculation stage, but he felt that these were subjects which should properly be taught by engineers rather than by the school masters, who were either pure physicists or mathematicians, and treated them from a very different point of view from that of the engineering teacher. When he mentioned plane and solid geometry in the first year's curriculum, he did not mean theoretical solid geometry but projective geometry, which was the basis of mechanical drawing.

Mr. EVANS: Do you do your drawing work in ink in the university?

Professor PIPPARD: In the past that has been done, but I am entirely against it.

Mr. EVANS: You are the first university professor that I have heard of who held that advanced view.

Wing-Commander CAVE-BROWNE-CAVE: I object. I also hold that view!

Professor PIPPARD: The older school of university teachers insisted on drawings being finished in ink and colour, but they had a good reason for it. He personally knew from experience when he was serving his apprenticeship in a civil engineering office that all the drawings were highly finished works of art on Whatman paper, lettered by hand. Stencils in those days were anathema, and if anybody had suggested their use on a finished drawing he would probably have been kicked out through the window into the street. That was the tradition of the old engineers, a tradition which was maintained until comparatively recently. During the past year certain distinguished engineers had asked him to stop students from doing that sort of work. That agreed entirely with his views, continued Professor Pippard, and he never allowed students to finish drawings in ink except in the case of survey work, where it was essential. For other work, good pencil drawings were sufficient.

Mr. EVANS: Should not tracing paper be used and blueprints taken?

Professor PIPPARD: The drawings were usually done in pencil, and if time permitted the students traced some of them on tracing cloth.

Mr. EVANS: The practice in the industry was to trace drawings in pencil on tracing cloth.

Professor PIPPARD: He regarded that as even better for certain purposes.

The CHAIRMAN: In proposing a vote of thanks to Professor Pippard, he said it should also be placed on record that the paper had produced a record discussion for the Society. Therefore, the best thanks of the Society were due not only to the author and the members of the industry who had spoken in the discussion, but also to the students who had taken part in it.

Mr. KENNETH G. MERRIAM (Assistant Professor of Aeronautical Engineering at the Worcester Polytechnic Institute, Worcester, Mass., U.S.A.) (*communicated*): The writer wishes to express his admiration of the logical and convincing manner in which Professor Pippard has handled his subject. From a general standpoint, it would seem that one would be bound to agree with the ideas and suggestions expressed in the paper. Especially satisfying to the writer were the comments relating to practical training and employment.

The exact curriculum proposed by Professor Pippard would be difficult to put into operation in many of the technical schools of the United States, although the general plan can be, and in some cases is, approached rather closely. The plan adopted by the Worcester Polytechnic Institute in 1928, and used with reasonable success since that time, is illustrated by the statement of curriculum appended to this discussion. A few explanatory comments relating to this curriculum may be useful.

It is the understanding of the writer that the three-year course of the English university is roughly equivalent to the four-year course of the American technical school. This must be considered in comparing the W.P.I. curriculum with that proposed by Professor Pippard.

The first three years of the W.P.I. curriculum are common to all students of mechanical engineering. The fourth year is available only to students who achieve a completely satisfactory record for their first three years at the Institute, which has meant that the fourth year class has been restricted to from six to eight students annually.

The instructors are not specialists. They are drawn from the regular engineering staff. In no case do they spend more than half of their instruction time in teaching aeronautics subjects.

To put this plan into effect, only one new laboratory was developed—the laboratory devoted to aerodynamics, which includes the necessary wind tunnel equipment. Some flying training was included in the plan for the first three years, but since then the flying training has been replaced by additional aerodynamics laboratory training and carefully arranged inspection trips to aeronautical centres near the Institute.

The student research project mentioned in the curriculum is of a reasonably ambitious nature. The student plans his project for six months before he actually attacks it. This is done under instructor guidance. He then spends one and one-half days per week for sixteen weeks executing the project, under careful supervision.

This plan works well for the exceptional student, and enables him to obtain a sound, but not too specialised, training in aeronautical engineering in the usual four-year period now allocated to undergraduate engineering training in the United States. It might be a feasible plan for many schools which cannot immediately adopt the more comprehensive plan outlined by Professor Pippard.

CURRICULUM, AERONAUTICAL ENGINEERING.

Worcester Polytechnic Institute, Worcester, Mass., U.S.A.

First Year Course.

Chemistry.	Descriptive Geometry.
Mathematics.	Modern Languages.
Engineering Drawing.	English.

Second Year Course.

Mathematics.	History.
Laboratory work.	Engineering Drawing.
Physics.	Surveying.

Third Year Course.

Economics.	Strength of Materials.
El. of Electrical Eng.	Materials of Construction.
Mechanism.	Machine Design.
Applied Mechanics.	Thermodynamics.
Laboratory work.	Political Science.

Fourth Year Course.

Aerodynamics Laboratory—intensive two-week summer course.

Electrical Eng. Laboratory.	Aircraft Instruments.
Laboratory Work.	Economics.
Applied Mechanics.	Graphics of Engineering.
Aerodynamics, Mechanics of Fluids, Hydraulics.	Theory and Design of Aircraft Structures.
Student Research Project.	Aircraft Engines.

Reply to Professor Merriam.—Professor PIPPARD, expressing his appreciation of the vote of thanks, said he was very grateful for the criticisms which had been made, which must be of the greatest possible value to the Society if the time came when further rules for the training of aeronautical engineers were formulated.

The remarks made by one of the contributors to the discussion led me to expect that the views I have put forward would receive nothing but adverse criticism from those conversant with the methods of training adopted in the United States of America.

It is therefore with very special appreciation that I have received Professor Merriam's comments. The scheme he outlines has many points in common with mine, but it is naturally difficult to make comparisons without knowing more about the details. It would appear that the four-year course described by Professor Merriam covers rather more ground than the normal three-year pass course of a British university, but not quite so much as my ideal for a four-year honours course. The fourth year seems rather heavily overloaded, as apparently the student approaches fluid mechanics and theory of structures for the first time, unless the elements of these subjects are treated as applied mechanics. I am in entire agreement with the introduction of a student research project in the fourth year, and adopted this plan myself in the University of Bristol. It is only possible or desirable, however, with the Honours student, and this point has been made clear by Professor Merriam.

It is a real pleasure to find that from a general standpoint, at any rate, teachers in America and in this country are in agreement. Methods and curricula will differ, but Professor Merriam's remarks indicate that our objects are the same: to train men in such a way that they will ultimately give the best service possible to the development of aeronautical engineering.

THE TREND OF DEVELOPMENT IN MILITARY AIRCRAFT

BY

SIR E. W. PETTER, M.I.Mech.E.,

Chairman of Petters Ltd.

Lecture delivered before the Yeovil Branch of the Royal Aeronautical Society, 13th December, 1934.*

The subject which I have chosen for my lecture this evening must be one of profound interest to all engaged in the design of aircraft to meet military requirements.

This country, with its great Empire sprawling over some three-quarters of the habitable globe and in many parts sparsely inhabited, must form an object of envy to nations cooped up within narrow confines with teeming and ever-increasing populations. We therefore cannot shut our eyes to the possibility of attacks being made upon us which we shall have no alternative but to defend ourselves against, if we are going to exist and hold the Empire which our forefathers have bequeathed to us.

The next consideration which we do not require professional training in military or naval tactics to appreciate, is that the predominant and indeed possibly almost solitary duty will fall upon the aviation arm of our military forces to resist attack and carry on a war.

The present moment seems to require that all engaged in this science should ask themselves the question: *Quo vadis*—whither goest thou?

We need to try to envisage what an aerial war will mean to us and what should be the line of development with which we should concern ourselves to enable our country to talk with its enemy in the gates.

During the past year or so an astonishing change has come over the scene so far as military aircraft is concerned. Machines which only two or three years ago were considered adequate are now recognised to be obsolete.

The war which began 20 years and ended 16 years ago, and which came at a period when military aviation was in its infancy, cannot now teach us very much. I do not say that it has no lessons, because the development which has taken place since 1918 does more or less accentuate the truth of the problems which revealed themselves during the Great War, which in its later stages developed, so far as aerial warfare was concerned, into the problem of the destruction of vital military centres by bombing aircraft, and that of defence against such tactics.

It appears that in any future war the same conditions will arise, and success will in all probability attend the operations of those who can use bombers to greatest effect and/or the side which discovers the antidote to bombing aircraft and succeeds in protecting its vital military and naval points against such attack.

It is a truism of all kinds of warfare that improvements in weapons of offence ultimately produce corresponding improvements in weapons of defence. There is almost inevitably a hiatus between the two, however, and that hiatus represents the danger period. It is very doubtful whether, at the present time, the true defence to the high-speed long-range day or night bomber has yet been discovered. It is possible, although at the moment it does not appear probable, that the answer to this problem may prove to be outside the sphere of aviation, that is

* Slightly abbreviated.

to say that some means of detecting and bringing down bombers by ground armament, or by some means of electrical or other scientific interruption of the engines or apparatus of an enemy aircraft may be discovered. But that is not yet, and for the moment those who are engaged in the science of military aeronautics have to concentrate on the endeavour to discover the aircraft answer to the heavy bomber.

The problem which presents itself in different countries is not always the same. For instance, assuming that of European countries, England, France and Germany are most likely to find themselves in some combination or another in mortal combat, then the problem which each of these countries has to face is not the same.

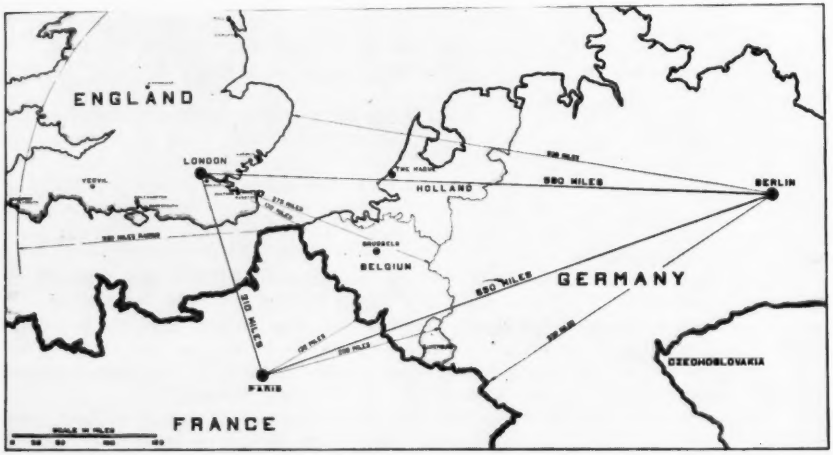

FIG. 1.

The military object will be very similar, namely that of inflicting the greatest possible injury upon the capital—being the seat of Government and nerve centre of the enemy country—and upon the places used for the congregation of great military units and stores, naval harbours, aerodromes and munition areas, while at the same time defending all its own similar interests so far as practicable against enemy attack. But the geographical position of the three countries which I have cited, and the differences in the distances of their vulnerable points from enemy frontiers, makes the conditions under which each will be engaged very different.

If you will refer to the chart Fig. 1, you will see that, in the case of Germany, her present frontier is within 200 miles of Paris, while if she were to overrun Belgium, as she did in 1914, she would be able to attack London from the air at a distance of not more than 130 miles.

France, in her relative position to Germany, finds her nearest point to Berlin some 330 miles.

From this it will be seen that France, in her effort to attack the enemy capital (assuming Germany to be the enemy) would need to have bombers having a minimum range of 660 miles if they are to come back, while a German machine with a minimum range of 400 miles could attack the French capital. The advantage obtained by this reduction of necessary range is obviously very great, as, assuming the two countries to be in the same stage of scientific development, the German machine could either be of much greater speed or carry a much greater weight of bombs.

When we come to our own case, the situation is even more serious. The distance from our coast nearest to Berlin as the crow flies is approximately 520 miles. If therefore we desire to attack Berlin from our own territory we must have machines with a minimum range of 1,040 miles, against the German machine attacking London from present German territory, 275 miles distant, minimum range 550; or, assuming that the attack comes from Belgian territory, a distance of 130 miles, minimum range 260 miles. A radius of 300 miles from the Belgian coast would cover the greater part of England and Wales, Devonport to Newcastle.

Since, then, as I have already said, the bomber holds the field as the most destructive offensive weapon in aircraft, it is not surprising to find that every country is concentrating upon a development of bombers suited to what it considers to be its need.

In passing, I would say that the bomber must not only be regarded as a weapon of offence. It may prove ultimately to be the only effective weapon of defence, because it is no use hiding from ourselves the fact that, notwithstanding the types of aircraft to which I shall presently refer as the accepted best types for dealing with bombers, under weather conditions which prevail in north-west Europe there is during the year a very large number of days when it is difficult to conceive of any effective defence, and it may prove that the fear of retaliation is indeed the only effective defence to bomber attack.

I had a very vivid impression of the difficulty in resisting bombing attack a fortnight ago when I travelled by Imperial Airways from London to Paris. When we arrived over Le Bourget there was an intense fog extending to at least 5,000 or 6,000 feet from the ground. We were able to get down low enough to distinguish the lights on the aerodrome, and once or twice got a glimpse of the outline of buildings, but we could not land. I could not help asking myself the question: What likelihood would there be of a machine sent up to head us off, unable to hear our engines by reason of the noise of its own, of finding us in three dimensions in a dense fog such as we were experiencing. The fog did not affect our navigation but only our landing, and the last thing that a bomber wants to do is to land on its objective.

The development of cloud flying, automatic piloting, and so forth, indeed puts the attacker (by which I mean the bomber) in a very strong position, and the worse the weather, the better for the attacker and the more difficult for the defender to neutralise him.

At the recent Paris Aero Show there was evidence of feverish activity in many countries in the development of high-speed long-range heavy fighting bombers. I shall be dealing with types of these machines later. I only at present want to emphasise their deadly character and the great difficulty of defence against them.

The accepted defensive aircraft at the present time is the machine of the interceptor or fighter class, and the development of machines of this type during the past two years has been remarkable. The underlying idea of the interceptor or fighter class of machine, and its usefulness in defence against bombing aircraft, is that by its speed it shall be able to overtake the bomber and either destroy it or cause it to deviate from its object.

The continuous increase in speed of machines of the bomber class is constantly bridging the gulf between it and the speed of the interceptor or fighter class. At the Paris Aero Show, for instance, we saw bombing machines such as the Bloch and Breguet having maximum speeds of 350 and 320 km. per hour respectively (roughly about 200 miles per hour), and the fastest single-seater fighter (the P.Z.L.) with a maximum speed of 416 km., say 250 m.p.h.

When it is remembered that the fighter or interceptor may have to climb to a height of 15,000 feet, and to a point sufficiently far ahead of the bomber

when first sighted to reach it at the altitude when attained, it will be realised that the margin between these two speeds is little enough (Fig. 2).

The influence of the developments in civil aviation upon military design is only just beginning to make itself felt, but there is no question that it is going to be very considerable. There are at the present moment commercial aircraft capable of conversion into bombers whose speeds approach very closely to those of the best single-seater fighters. I shall have more to say about this later.

Except in so far as bombing retaliation may prove to be the best defence against hostile attack, it would seem that our best course in this country is to concentrate upon high-speed interceptor and fighting machines, of which great numbers will be needed if our defence is to be effective.

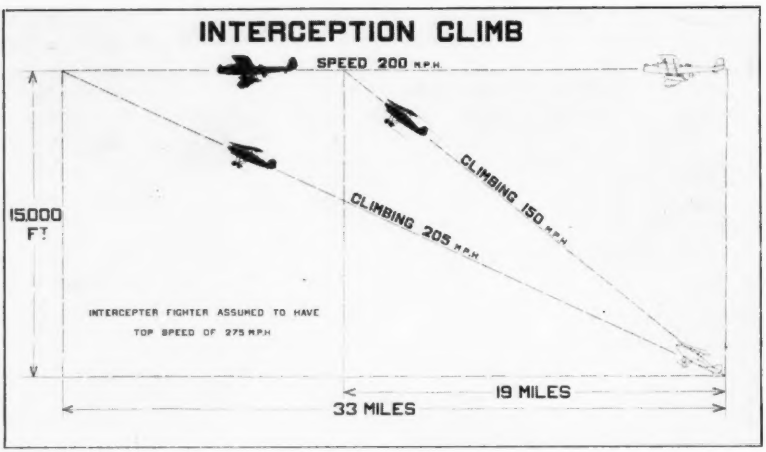

FIG. 2.

From the chart I have shown you it will be realised that interceptors and fighting machines must have:—

View (especially upward view);
Manœuvrability;
Speed.

But the greatest of these is speed.

Napoleon said that an army fought on its stomach. It is equally true to say that an aircraft is dependent upon its engine, and the development of the single-seater fighter, which appears at the moment to be of paramount importance to us, is dependent upon the ability of our engine designers to give us engines equal to any of those that can be produced in other countries.

At the moment I think it must be admitted that we are somewhat behind in this respect. There may be, and I think no doubt are, what may be considered to some extent sound reasons for this, the most effective of which is, I believe, the very strong effort at national economy which we have made during the past four years. Our Air Ministry has laid it down that only engines shall be constructed which have long periods of usefulness between overhaul, and this definitely limits the power obtainable from given cylinder dimensions. It was freely stated at the Paris Exhibition that the useful life of one or two of the engines which were much admired was probably not more than 25 flying hours.

If a period between overhaul of 150 hours was insisted upon, the rating of those engines would have to be correspondingly lowered. An outstanding instance of what I mean is the engines used in the Schneider Cup Trophy Race, which, with a normal rating of about 600 h.p., were used to develop over 2,000 h.p. with a useful life of no trouble duration of from 3-7 hours. You must decide what you want, and if you are willing to limit your life between overhaul to such a period as 25 hours, you can of course get a very much better performance than if you insist upon 150 hours. During the last war I believe 25 hours was considered to be the useful life of military aircraft, and, as a matter of fact, 25 hours leaves room for a great deal of war service. For instance, in a machine developing 250 miles per hour, you have 6,250 miles of flying capacity before you have used up your 25 hours. This is a lot of flying.

One rather shudders to contemplate what would happen if the question of flying hours came to be considered a more or less negligible one. In that case we might have machines to deal with having speeds of 350 to 400 miles per hour, and we cannot rule out the possibility that a military aircraft may some day come to be considered simply as a humanly-directed projectile, and interest in its future use may become of relatively small importance.

It must not be thought that the bomber is going to take the attack of the fighter lying down. The modern bombers are equipped with weapons of offence which at least give them a sporting chance against their attackers. Not only so, but there are indications that the bomber itself will be used as a fighting weapon. One of the outstanding features of the Paris Show was the advent of the 20 mm. cannon with which two or three bombers were equipped. This cannon is capable of firing a $\frac{3}{4}$in. diameter shell at the rate of 600 rounds per minute, and is considered capable of breaking up the formation of enemy aircraft whilst keeping out of range of machines equipped with lighter armament. The development in armament of aircraft is portentous, and in itself introduces all kinds of new problems into the question of military aviation. In passing, I should mention that single-seater fighters are also being equipped with the 20 mm. gun.

I think what I have said should be enough to cause designers to appreciate something of the extent of the problems which present themselves to them at the present time, and which may become realities in the near future.

It will be interesting at this stage to consider some of the types of aircraft for the two purposes which I have mentioned which are available in different countries, but first of all I would say a word about engines. The two outstanding engines at the recent Paris Show were undoubtedly the Hispano-Suiza 12-cylinder vee type water-cooled engine, developing 900 h.p. at 2,400 r.p.m. at an altitude of 13,100ft. and weighing 455 kilogrammes (say, 1,000lbs.), and the Gnome and Le Rhone 14-cylinder radial air-cooled engine developing 900 h.p. at 2,300 r.p.m. at an altitude of 11,800ft. and weighing 520 kilogrammes (say, 1,050lbs.). At the present moment, so far as I am aware, we have no engines of equal capacity. Both these engines are used in single-seater fighting machines which were on exhibition at the show.

The nearest British engines that we have at present to put up against these two types are, I believe:—

The Rolls-Royce Goshawk.—Weight, 975lbs. Present maximum 650 h.p., with hopes of increase.

The Bristol sleeve-valve Perseus.—Weight, 1,010lbs. Present maximum 835 h.p., also with hopes of increase.

I would here like to say that in the preparation of this lecture I have found the subject so vast that I am compelled to confine myself to a more limited field than my title seems to suggest. I cannot deal with the naval side of aviation—seaplanes and flying boats, aircraft for anti-submarine patrol, ship planes for catapulting and deck landing, etc. Neither can I deal with specialised aircraft, such as troop carriers and the like.

A full review of the subject would also require discussion upon the relative merits of monoplanes and biplanes, and the material of which various types of machines should be constructed, the methods of manufacture, etc. But all this I must leave, as it would take me far beyond the limits of a lecture such as this.

I have endeavoured to deal with such subjects as have appeared to me of the greatest interest and importance at the present time, and will now proceed to show you the slides which have very kindly been prepared for me.

The following are some of the latest types of machines, with such particulars about them as are available.

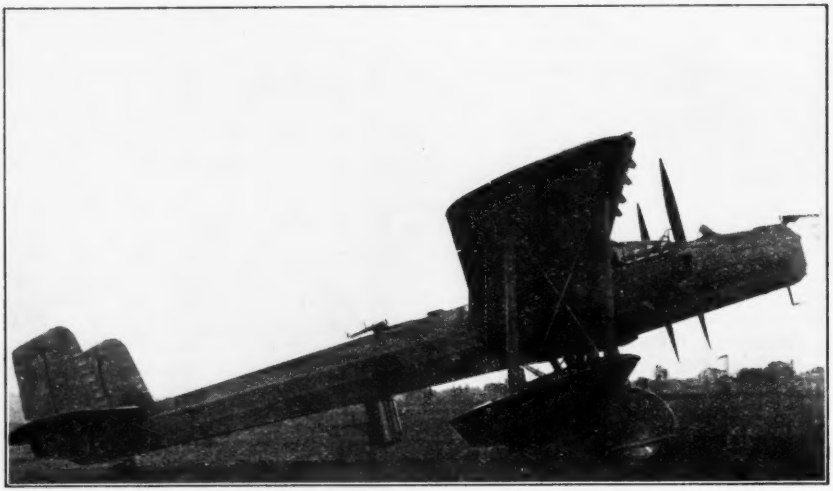

FIG. 3.

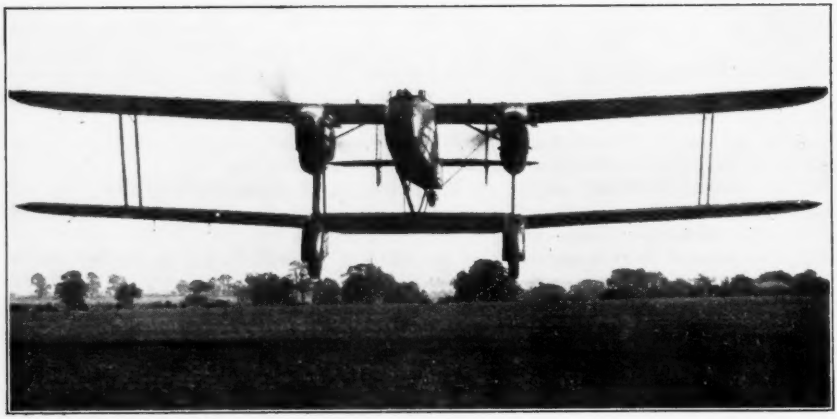

FIG. 4.

Figs. 3 and 4.—Name: Handley Page Heyford. Nationality: British. Two Rolls-Royce Kestrel engines. Maximum speed: 142 m.p.h. Range: 920 miles. Bomb load: 1,600lbs. Alternatively, 400 miles with bomb load of 3,200lbs.

FIG. 5.

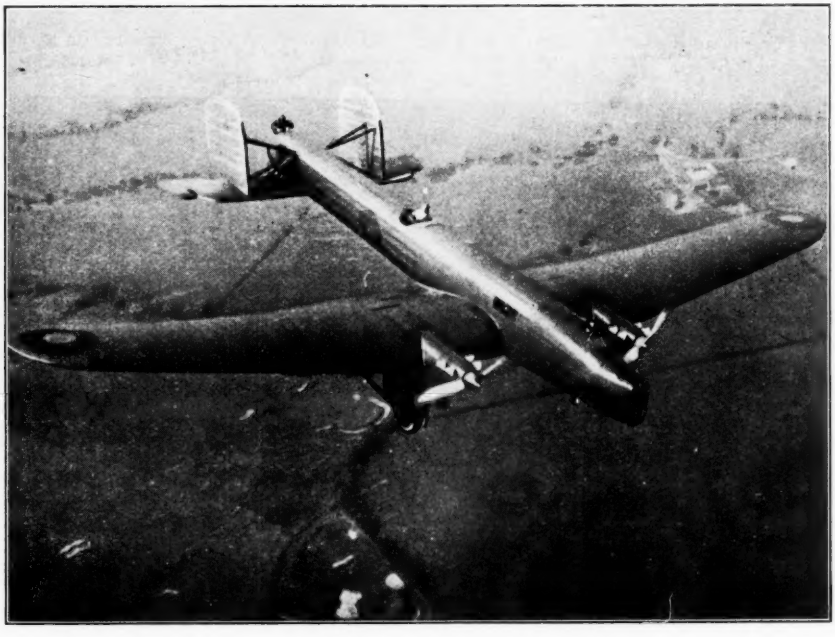

FIG. 6.

Figs. 5 and 6.—Name: Fairey Hendon. Nationality: British. Twin engine (various types). Speed: Probably about 145 or 150 m.p.h. Performance particulars secret.

FIG. 7.

Fig. 7.—Name: Hawker Hart. Nationality: British.
Single-engined Rolls-Royce Kestrel. Standard two-seater fighter or day bomber. Speed: 186 m.p.h.

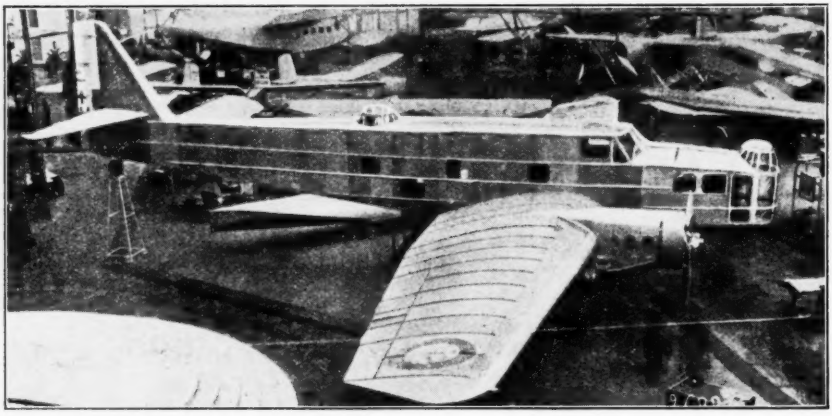

FIG. 8.
The Bloch high-speed bomber from above.

Fig. 8.—Name: Marcel Bloch. Nationality: French.
Two 740 Gnome and Le Rhone K.14 geared and supercharged engines. Maximum speed: 175 m.p.h.
Now in production for French Air Force.
Alternative model fitted with two Hispano-Suiza 12-cylinder geared and supercharged water-cooled engines. Speed: 210 m.p.h.

FIG. 9.

Fig. 9.—Name: Breguet. Nationality: French.
Two Gnome and Le Rhone engines, 14-cylinder; total 1,800 h.p. Speed: Stated to be 192.5 m.p.h.

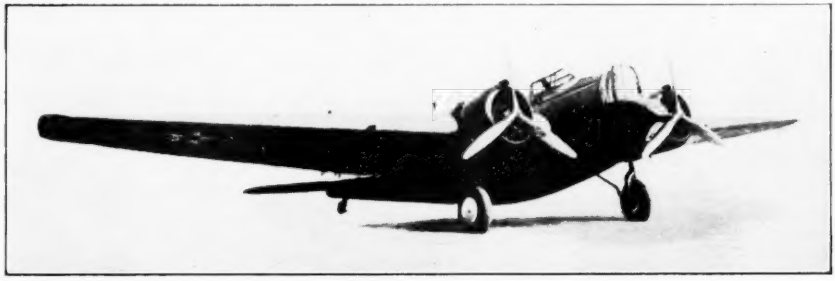

FIG. 10.

Fig. 10.—Name: Martin. Nationality: American.
Twin-engined. Fixed mid-wing monoplane. Speed: Probably about 200 m.p.h.

Forty-eight of these machines have been delivered to U.S. Army Air Corps, and 81 on order. Of the first 48, 15 were fitted with Wright Cyclone engines and 33 with Pratt and Whitney Hornet.

I have already referred to the influence of commercial aviation upon military design which is beginning to assert itself very strongly and will in future have even greater effect. The requirements of fast passenger and mail-carrying aircraft are almost identical with those of bombers. Civil aircraft of the kind to which I am referring must have speed, carrying capacity, long range and reliability. Recent developments, particularly in America, have opened the eyes of Governments, including our own, to the possibility of the adaptation of civil aircraft to military requirements.

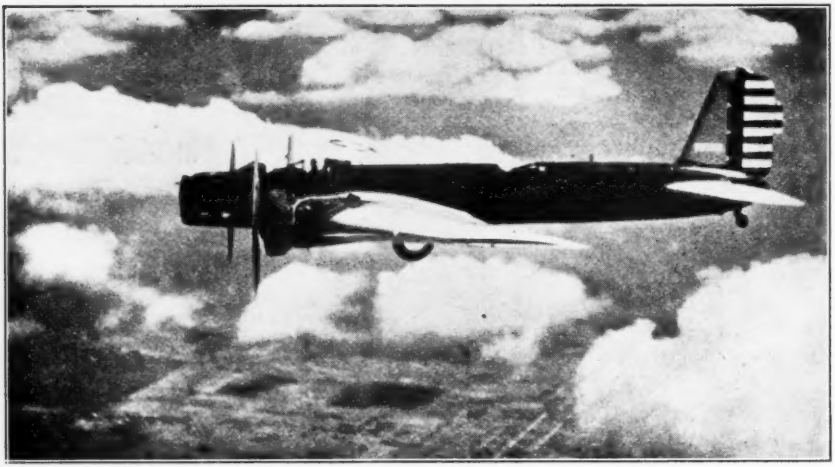

FIG. 11.

The Boeing Bomber Monoplane (two 575 h.p. Pratt and Whitney "Hornet" engines).

Fig. 11.—Name: Boeing. Nationality: American.
Twin-engined bomber. Two 575 Pratt and Whitney Hornet. Speed: 186 m.p.h. Service ceiling: 20,150ft. Absolute ceiling: 21,900ft.

Other machines which might be mentioned are:—

The Liore and Olivier Leo 206 four-engined machine; speed about 175 m.p.h.

Farman.—Four-engined night bomber having a speed of 171.4 m.p.h.

Potez.—Low wing cantilever monoplane fitted with four 840 h.p. Hispano-Suiza 12-cylinder geared and supercharged engines mounted in tandem pairs above each wing. Said to have a speed of 198 m.p.h.

In America and Germany commercial aircraft has been developed, having, with the other requisite conditions, speeds of well over 200 m.p.h. This fact has stimulated the military mind in the United States, who find that the clean design of the modern American transport machine can be well adapted to carry military loads and be put to military use. Our own Government has become wise to the same fact, and there is no doubt that the class of machine which has been developed in America as a direct result of commercial work will find its way into the Royal Air Force.

I am now going to show a few outstanding examples of these commercial machines capable of conversion to military use.

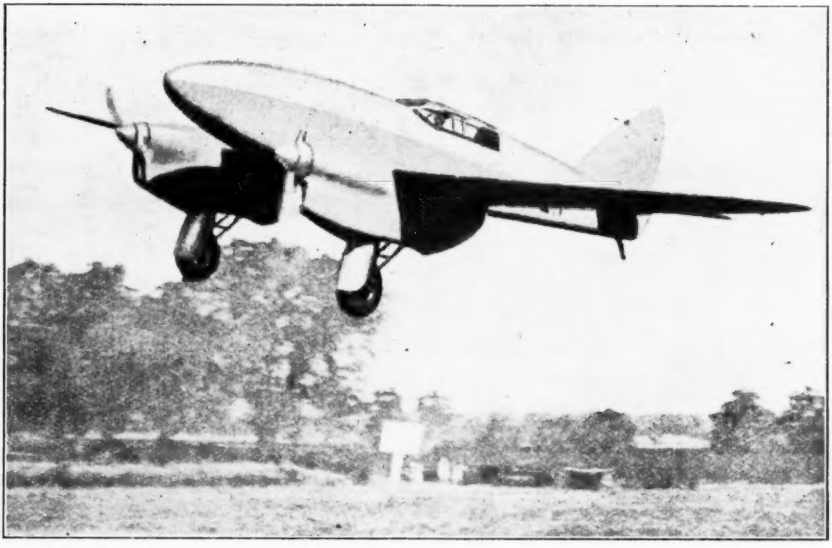

FIG. 12.
The De Havilland "Comet."

Fig. 12.—Name: De Havilland Comet. Nationality: British.

This is a long-range twin-engined low wing cantilever monoplane, and the winner of the recent England-Australia Race.

It is fitted with two Gipsy Major six-cylinder engines.

It has a maximum speed of 240 m.p.h. at sea level, and a still air range of 3,100 miles for the purpose for which it was used, and is said to be capable of carrying 1,000lbs. of bombs 1,000 miles at 200 m.p.h.

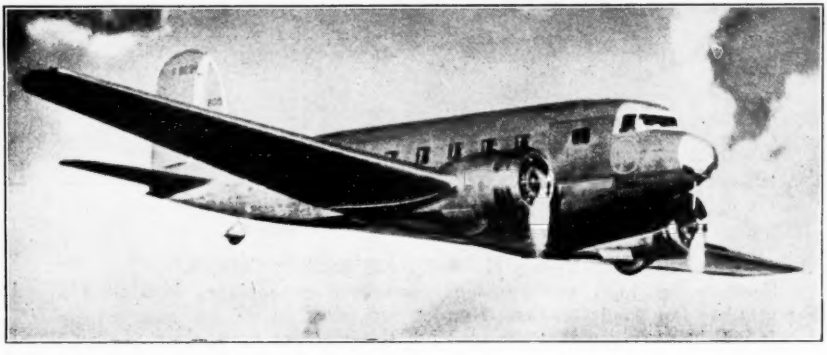

FIG. 13.
The Douglas "Airliner" Twelve-passenger Cabin Monoplane (two 710 h.p. Wright "Cyclone" engines).

Fig. 13.—Name: Douglas. Nationality: American.

This is a twin-engined commercial monoplane. It has about 2,800lbs. pay load.

Maximum speed: 213 m.p.h. and a range of probably about 1,500 miles.

This machine also did very well in the England-Australia Race, coming in second.

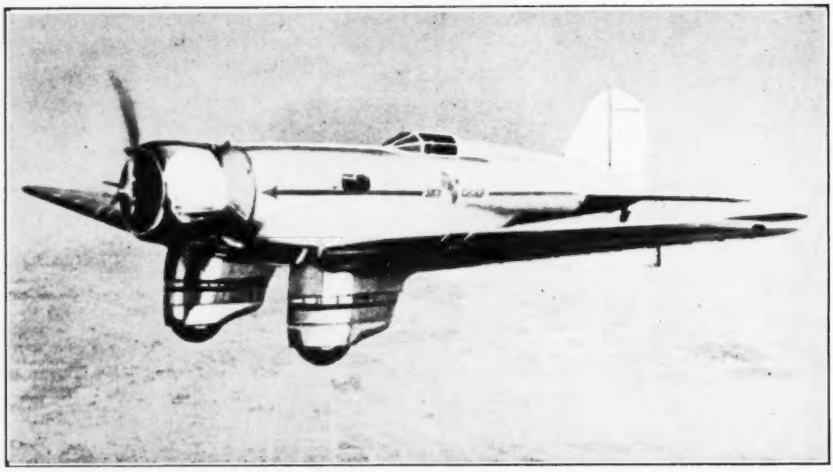

FIG. 14.

Fig. 14.—Name: Northrop. Nationality: American.

Single-engined freight or passenger-carrying monoplane. Maximum speed: 210 m.p.h. Range: 174 m.p.h. at 1,550 miles.

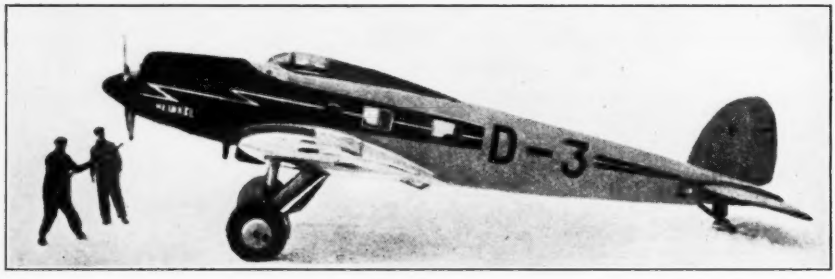

FIG. 15.

Figs. 15 and 16.—Name: Heinkel. Nationality: German.

Seven-seater high performance commercial monoplane. Maximum speed: 234 m.p.h. Pay load: 880lbs. Range: 620 miles.

It will be observed that the speed of this machine approximates very closely to that of the best single-seater fighters.

We now come to the machines whose task it will be to deal with attacking aircraft.

Firstly: The single-seater fighter.

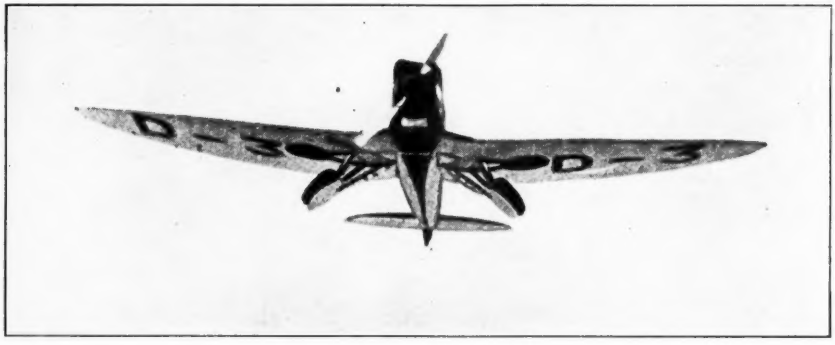

FIG. 16.
Heinkel.

FIG. 17.

Fig. 17.—Name: Gloster Gauntlet. Nationality: British.

This is an experimental Gloster Gauntlet in competition with our F.7/30 single-seater fighter.

Fig. 18.—Name: Gloster Gauntlet. Nationality: British.

Single-seater high altitude day and night fighter. Fitted with Bristol Mercury engine and is just being put into production for British Air Force.

Speed: 231 m.p.h. Climbs to 20,000ft., 9 mins. 25 secs.

Probably our fastest machine.

FIG. 18.

FIG. 19.

Figs. 19 and 20.—Name: Hawker Super-Fury. Nationality: British.

This machine is fitted with a single Kestrel engine, normal output 600 h.p. It has tapered wings of shorter span than the standard model. Has been credited with a top speed of about 230 m.p.h.

During 1934 this machine has been further modified and a Rolls-Royce Goshawk engine installed, with full steam cooling system. Experiments with this machine are still in progress.

Steam cooling has not yet been passed out as satisfactory, but if it should be, it will remove one great difficulty which the water-cooled engine has in competition with the air-cooled.

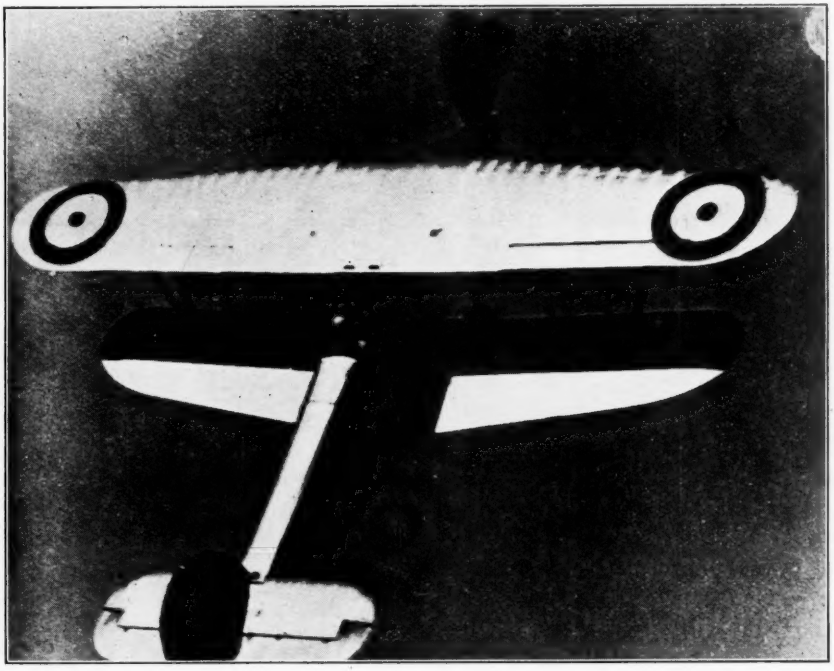

FIG. 20.
Hawker Super-Fury.

Fig. 21.—Name: Dewoitine. Nationality: French.

Fitted with 860 Hispano-Suiza 12-cylinder motor cannon.

This machine is stated to have a maximum speed of 245 m.p.h., and is fitted with a gun of 20 mm. firing a shell $\frac{3}{4}$in. diameter.

The slide shows the old form of undercarriage. It has recently been fitted with an undercarriage consisting of two single struts embodying an oleo leg with streamline fairing for the wheel.

Guns are being fitted on the wing. Fighters are carrying four, six and eight guns, all firing from the wing, and that helps very much in getting a clean fuselage and improved performance.

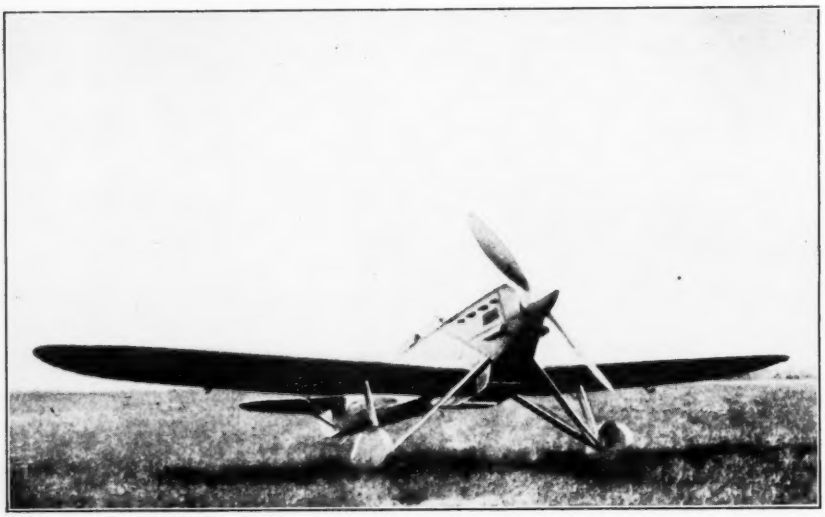

FIG. 21.
Dewoitine.

FIG. 22.

Fig. 22.—Name: Avia. Nationality: Czecho-Slovakia.
This machine has the 12-cylinder Hispano-Suiza 850 h.p. water-cooled engine. The pilot is completely enclosed. Maximum speed: 241 m.p.h.

Fig. 23.—Name: Letov. Nationality: Czecho-Slovakia.
This machine is fitted with a 14-cylinder Gnome and Le Rhone Mistral engine developing 900 h.p. Has a maximum speed of 250 m.p.h.

FIG. 23.
Letov.

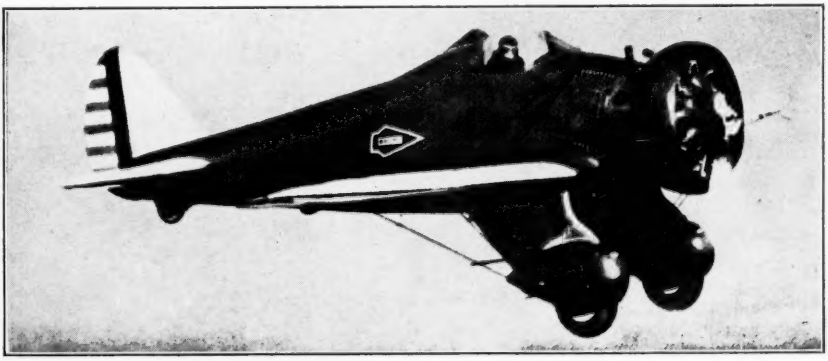

FIG. 24.
The Boeing P-26A Single-seat Fighter Monoplane
(525 h.p. Pratt and Whitney "Wasp" engine).

Fig. 24.—Name: Boeing. Nationality: American.
Single-engined Pratt and Whitney. Has a maximum speed of 230 m.p.h. Low wing monoplane.
Fig. 25.—Name: P.Z.L. Nationality: Polish.
700 h.p. Gnome and Le Rhone Mistral major, radial air-cooled engine.
Single-seater fighter monoplane. Maximum speed: 252 m.p.h.

Other machines which might be mentioned in this category are the Italian Fiat, with a maximum speed of 230 m.p.h.; American Curtis Hawk, similar speed; and there are, of course, many others which I have not time to mention.

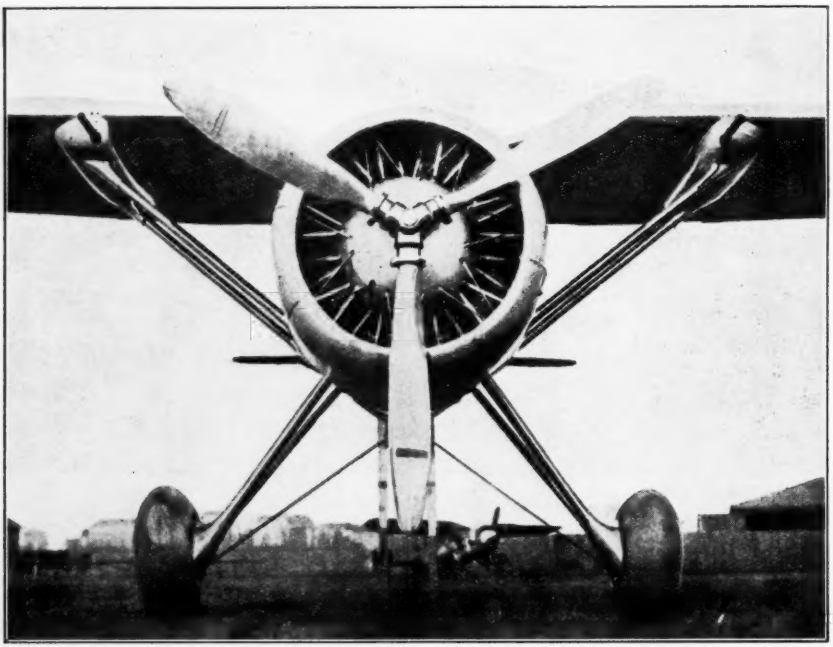

FIG. 25.

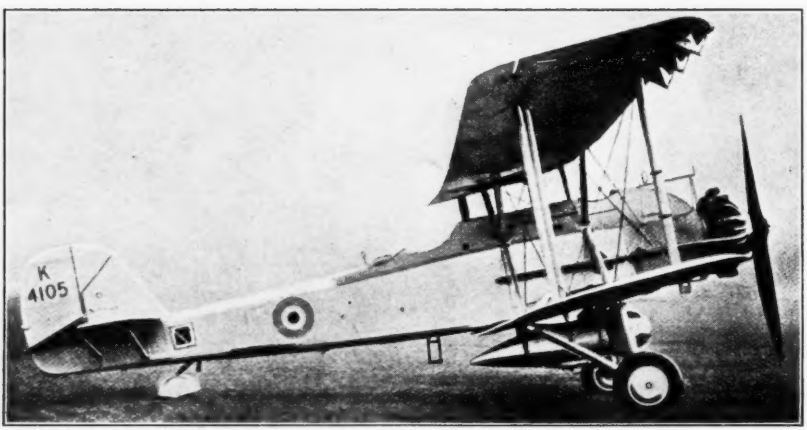

FIG. 26.

It is too much to think that the whole of aerial war is going to be concerned with bombing and single-seater fighters. The great disadvantage of the single-seater machine is the fixed gun, which means that the directional line of fire must always be in the same direction as flight; and there is no doubt that there will be plenty of room for other machines which can fire from all angles.

Two-Seater Fighters, Reconnaissance and General Purpose Machines

Fig. 26.—Name: Vickers Vincent. Nationality: British.

Single-engined Bristol Pegasus two-seater torpedo-carrying and bombing biplane. It has a maximum speed with bomb load of 141 m.p.h.

This machine is one which we had hoped would be superseded by our P.V.7, which had the unfortunate accident last August. Our machine carried approximately the same load about 30 miles faster.

It was one of the great misfortunes of our history that this machine should have been broken up in a T.V. dive in gusty weather, for which it was not designed and was not strong enough.

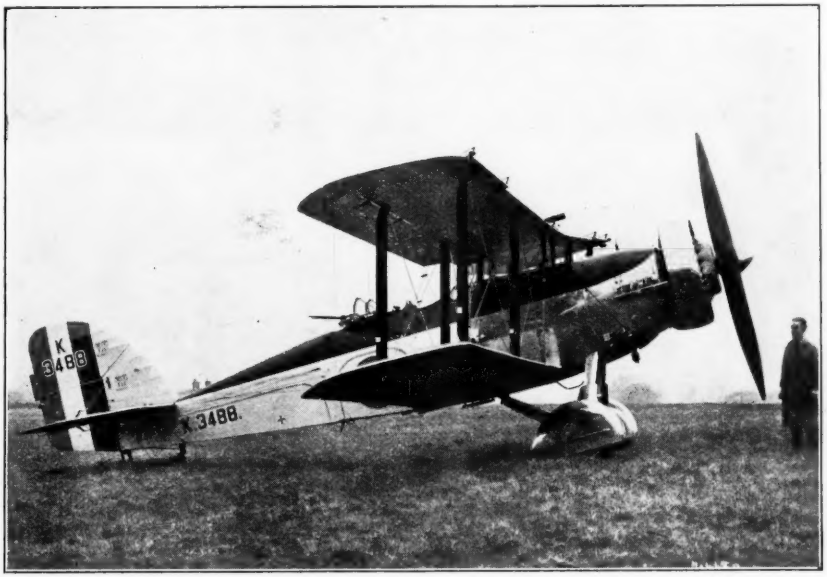

FIG. 27.

Figs. 27 and 28.—Name: Westland Wallace. Nationality: British.

Fig. 27, without enclosed cockpit. This is a machine of which I venture to say the merits have never been fully appreciated by our Air Ministry.

Fitted with Bristol Mark III Pegasus engine, it has a maximum speed of 168 m.p.h.

The Wallace has the misfortune of being looked upon as a glorified Wapiti, and the Wapiti as a glorified D.H.9A., and the machine has never been able to get away from being looked upon from that point of view.

Fig. 28 shows it with enclosed cockpit, which has greatly improved the machine and enabled the rear gunner to fight at high speeds.

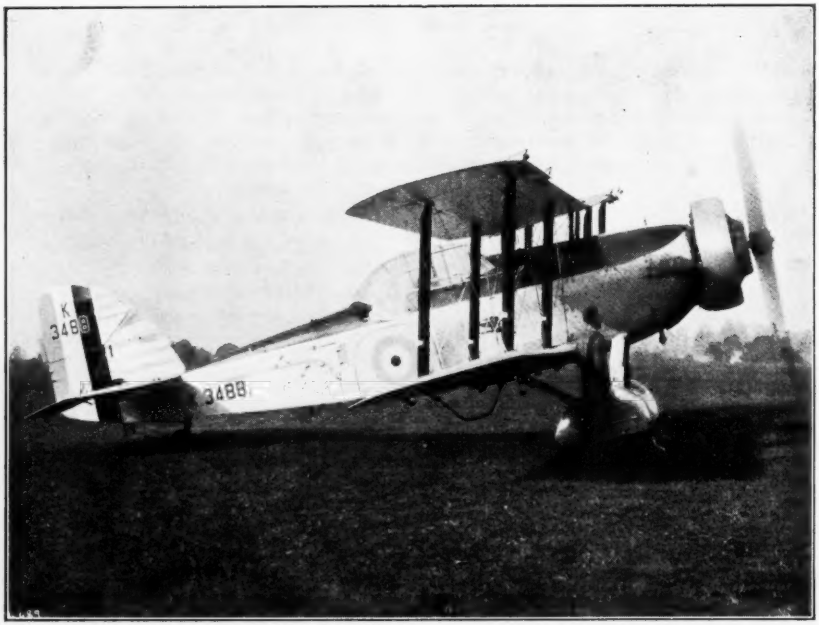

FIG. 28.

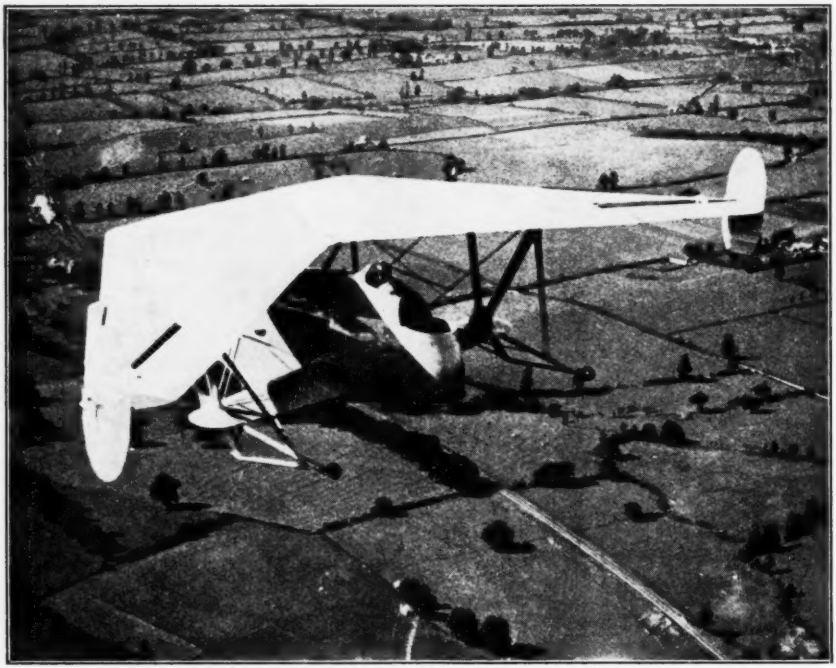

FIG. 29.

Fig. 29.—Name: Pterodactyl Mk. V. Nationality: British.

This is a very interesting machine upon which we have spent a great deal of time and money. As a two-seater fighter it has advantages possessed by no other type of machine.

In the picture the machine is shown as a tractor fitted with Rolls-Royce Goshawk engine. We are not allowed to mention the performance, but I may say that so far its maximum speed has not quite reached 200 m.p.h.

The view from the gunner's cockpit and the ability which the gunner has to use his gun, will be fully appreciated from the photograph.

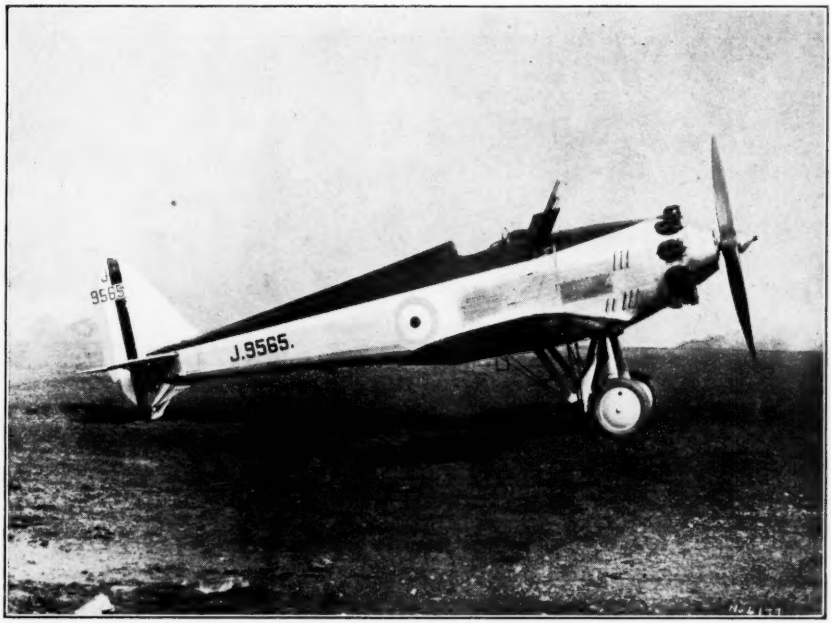

FIG. 30.

This machine has also been designed as a pusher with the cockpit in front. In the case of a new invention, you must not only have the advantages of the new invention, but must see whether in all other respects it is equal to competitive projects.

I may mention that there is a " hush-hush " mechanical, power-driven gun turret being designed for this machine, and we believe the whole combination will be something to be reckoned with in the near future.

Fig. 30.—Name: Westland C.O.W. Gun Fighter. Nationality: British.

This also is a very interesting machine, and we believe its good points are beginning to attract serious attention.

It is still undergoing trials at Martlesham.

It is fitted with a 37 mm. gun that is 1½in. bore, and fires a 1½ pdr. shell.

The speed of the machine, which is at present fitted with an old type Bristol Mercury IV engine, is 185 m.p.h. This could be considerably increased if the latest type of Bristol Perseus sleeve-valve engine were embodied.

Figs. 31, 32 and 33.—Name: Cierva Autogiro C.30. Nationality: British.

In conclusion I am showing a machine of great interest to us, the Autogiro C.30, fitted with Armstrong-Siddeley Genet seven-cylinder air-cooled radial engine.

It has been said that the autogiro has no military value, but a number of them have been ordered by the Air Ministry for Army co-operation and other military uses.

It there is a military future for this type of aircraft for specialised duties, then here again we have the probability of civil types being convertible to military purposes. Mention might, therefore, be made of the 4/5-seater autogiro which

FIG. 31.

we have just built, and of the smaller two-seater which is now nearing completion in our works.

In conclusion, what are the requisites necessary to enable this country to hold its own in the technical development of military aircraft?

First of all I put the allocation of a requisite sum of money for the purpose. When we consider the paramount importance to these islands of aerial defence, our people and their Government must be awakened to the fact that any further niggardliness in this respect may produce irremediable disaster.

Since the war, this country has spent some £1,200,000,000 on its defence services, with, I venture to say, a wholly inadequate appropriation on the aviation side. Our expenditure upon our three great Services for the year 1933-34 was:—

For the Navy	£53,570,000
,, ,, Army	£37,650,000
,, ,, Air Force	£17,426,000

That a country so vulnerable as we are should spend only about 15 per cent. of its total military appropriation upon the arm which common-sense indicates

must bear the greatest burden of defence in any war in which we are likely to be engaged, seems to me to show a total lack of proportion.

I by no means wish to belittle the importance of our Navy, but how are we going to use our Navy when every harbour in which it can ride, and might be available to do effective work, is at the mercy of aerial attack? How are we going to feed our population when every port to which food can be brought is in the same precarious situation? I do not hesitate to say that if this country is not willing to find the money necessary for aerial defence, it must be prepared to give up the position to which its history has brought it.

It is nothing more than the truth to say that the economy policy of our Government in respect of aircraft development has led to a most dangerous

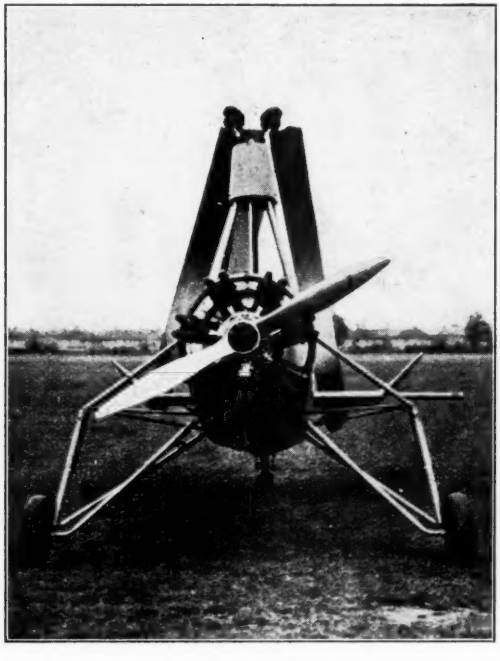

FIG. 32.

situation at the present time. It has been responsible for the effort to make one type of aircraft fulfil a number of quite different conditions, with the result that you get no one type equal, or even approximately equal, to that specially designed for a specific purpose.

There are signs that under pressure of informed opinion the folly of this policy is beginning to be recognised, and it is none too soon.

When I was in Paris a short time ago I had the opportunity of going over a very well-organised French factory, and one could not admire enough the jigging and tool work that had been spent on their production machine. We were told that £40,000 had been spent on jigs alone, and then, in a stage aside, the head of the concern told me, "And the Government paid every penny of it." A country that is willing to do that can get what it wants.

The next desideratum is a large measure of freedom for the designers and a much greater measure of latitude than they have had in the past. This presupposes that designers will take the trouble to master the problems that confront them and appreciate the requirements which their machines must fulfil, so that they may be able to design really practical machines of clean design and good flying qualities with the requisite features as regards speed and carrying capacity to meet every conceivable need.

FIG. 33.

The barriers which at present lead to unreasonable delays in the development of new types of aircraft must be removed, and the niggardly treatment to which contractors have been subjected and which has placed upon them the major portion of the heavy burden of expense of development work, must give place to a policy of encouragement similar to that extended to aircraft manufacturing firms on the Continent and elsewhere, or the effort to bring ourselves into line with what is being done in other countries will fail.

A NEW METHOD FOR CALCULATING THE CLIMBING SPEEDS OF AEROPLANES OF GREAT CLIMBING CAPACITY

BY

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Royal Dutch Air Force in Dutch East Indies

(a) Introduction

For the calculation of the climbing speeds of aeroplanes several methods are in use, which, as is well known, do not yield quite accurate results when applied to machines with great climbing capacities, and give rise to inaccuracies which become of greater importance with increasing climbing capacity of the plane.

The climbing speed, up to the present, has not been great in respect to the forward speed used when climbing, so that for the calculation of the climbing speeds the method fairly generally used and described in the " Handbook of Instructions for Airplane Designers," from the U.S. Army Air Service, could be used without serious objections. It has, however, been found desirable to look for a better method for calculating the climbing speeds, owing to increasing engine powers accompanied by decreasing drag coefficients of the aeroplanes, as well as to the introduction of variable pitch airscrews.

With the aid of the method to be described below, the climbing speed of every aeroplane, making use of the exact normal information can be determined with great accuracy without materially increasing the amount of work involved.

(b) Notations

G = aeroplane weight in kg.
F = wing area in m.^{2}.
N = engine power in h.p.*
n = rev. per minute.
η = airscrew efficiency.
D = airscrew diameter in m.
v = flying speed in m./sec.
w = rate of climb in m./sec.
θ = climbing angle.
L = wing lift in kg.
W = aeroplane drag in kg.
ρ = air density in kg. sec.^{2}/m.^{4}.
q = pressure $\frac{1}{2}\rho v^2$.
c_a = lift coefficient when climbing $= L/\frac{1}{2}\rho v^2 F$.
c_w = drag coefficient when climbing $= W/\frac{1}{2}\rho v^2 F$.
c_{wh} = lift coefficient for horizontal flight.
c_{ws} = climbing speed coefficient $= wG/qvF$.

* 1 h.p. = 75 kg.m.

(c) Derivation of the Formulæ

The power delivered to the aeroplane by the airscrew ηN can be divided into the power Wv necessary for overcoming the air resistance and the power wG necessary for climbing, so that

$$75\,\eta N = Wv + wG \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and because

$$w = v \sin\theta$$

we may also write

$$75\,\eta N/v = W + G \sin\theta \quad . \quad . \quad . \quad . \quad . \quad (2)$$

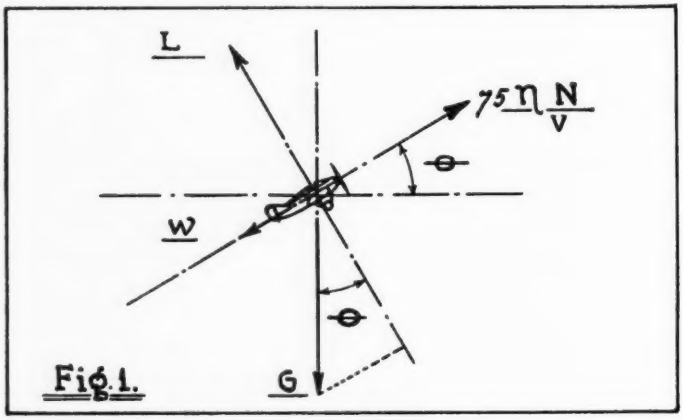

Fig. 1.

As, according to Fig. 1, the forces acting perpendicularly to the direction of flight must be in equilibrium :—

$$L = G \cos\theta \quad . \quad . \quad . \quad . \quad . \quad (3)$$

hence

$$G \sin\theta = \sqrt{(G^2 - L^2)} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

With the aid of (4) and the well-known aerodynamic equations :—

$$W = c_w q F \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

and

$$L = c_a q F \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

we may write (2) in the following form :—

$$75\,\eta N/v - c_w q F = \sqrt{(G^2 - c_a{}^2 q^2 F^2)} \quad . \quad . \quad . \quad (7)$$

By squaring both sides of equation (7) we find after rearrangement :—

$$c_a{}^2 + c_w{}^2 - 2c_w\,75\,\eta N/vqF + 75^2\,\eta^2 N^2/v^2 q^2 F^2 - G^2/q^2 F^2 = 0 \quad . \quad . \quad (8)$$

Let us now assume, that the aeroplane is flying with engine " all out " at a certain unknown climbing angle, at a definite altitude h and with a definite speed v. Then, the number of revolutions per min. n for a given engine and a given airscrew, being a function of the position of the throttle, of h and of v, has a definite value, and therefore the engine power N, as this again is a function of n and h. The airscrew efficiency η is also known, because η is a function of v/nD, D being the airscrew diameter. Finally, q is known, whereas the aeroplane weight G and the wing area F are constants.

Supposing now, that the aeroplane is flying at a certain elected—arbitrary—altitude with throttle fully open—a restriction which does not interfere with the exact determination of the climbing times—then, in equation (8) there are only terms which are dependent upor v, except c_w and c_a.

This being the case, equation (8) represents a series of circles in the $c_w - c_a$ plane, the centres of which are situated on the c_w axis.

Let us consider one of the circles of the series and, to this end, let us shift the c_a axis in such a way that this axis goes through the point :—

$$c_w = 75\,\eta N/vqF \text{ and } c_a = 0,$$

then by arranging (8) with the aid of

$$c_w = c_{w_1} + 75\,\eta N/vqF \quad . \quad . \quad . \quad . \quad . \quad (9)$$

the equation for this circle becomes

$$c_a^2 + c_{w_1}^2 - G^2/q^2F^2 = 0 \quad . \quad . \quad . \quad . \quad (10)$$

Further, assuming that

$$G = c_{ah}qF \quad . \quad . \quad . \quad . \quad . \quad (11)$$

in which c_{ah} is the lift coefficient of the aeroplane wing when flying horizontally at speed v—belonging to pressure q—then (10) will read as follows :—

$$c_a^2 + c_{w_1}^2 = c_{ah}^2 \quad . \quad . \quad . \quad . \quad . \quad (12)$$

from which it will be clear that the radius of this circle has a simple meaning.

The circle of (12) described in the form of (8) will intersect the $c_w - c_a$ curve of the aeroplane, the polar curve, in zero one or more points.

Leaving out of consideration those intersections which yield a negative lift-coefficient and also those intersections situated in the area in which the wing is stalling, then, with usable aerofoils, only one or zero intersections will be left.

If no intersections are available, this indicates, that for the speed chosen no values of c_a and c_w can be found which satisfy the polar curve of the aeroplane.

If the centre of the circle lies on the c_w axis between the polar curve and the c_a axis, this indicates that the selected speed is greater than the speed the aeroplane can reach with the available engine power, so that climbing will be out of the question; if, however, the centre lies on the other side of the polar curve, then the selected speed is too small for flying with engine " all out."

In the latter case the polar curve can lie completely inside the circle to be constructed which means that continual flight at the selected speed is quite impossible; or the polar curve can lie completely outside that circle, which indicates that only with throttle fully open no continual flight at the selected speed is possible, because there will be an excess of engine power at that position of the throttle, even when climbing vertically at that speed.

If a point of intersection of circle (8) with the polar curve can be found, three cases can be encountered, to wit :—

(*a*) The value of c_w in the point of intersection of circle and polar curve is greater than the value of c_w in the centre of the circle, being $75\,\eta N/vqF$; in this case condition (7) is not satisfied.

(*b*) The value of c_w in the point of intersection under discussion is equal to $75\,\eta N/vqF$; in this case (7) is satisfied only by putting $G = L = c_a qF$.

(*c*) The value of c_w in this point is smaller than $75\,\eta N/vqF$; in this case (7) has been satisfied.

Obviously, in case (*a*) the selected speed is again too great for continual flight; in case (*b*) it is exactly equal to the maximum aeroplane speed; whereas in case (*c*) the selected speed is smaller than the maximum speed, flying is possible and an excess of engine power is available for climbing.

Because in the latter case the co-ordinates of the point of intersection of circle and polar curve satisfy condition (7), it follows, that in that case the co-ordinates of the point of intersection of circle and polar curve are lift and drift coefficients of the aeroplane, if the aeroplane is flying at the selected speed with throttle fully open.

If the drag coefficient c_w is known, it is a simple matter to determine $\sin\theta$ with the aid of equations (5) and (2), from which at the same time the climbing rate $w = v \sin\theta$ is known.

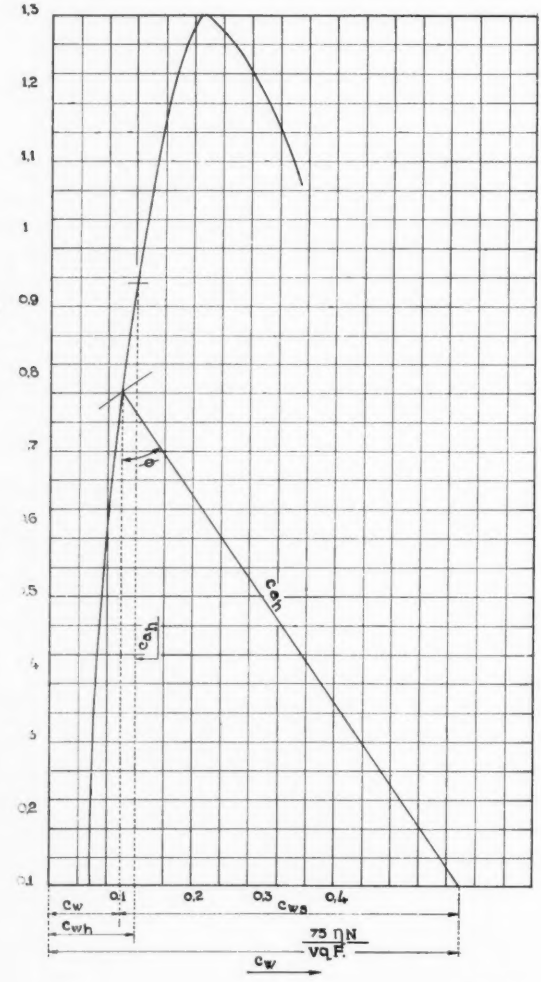

Fig 2.

However, we can also determine w in a somewhat different manner, and to this end we write:—

$$c_{w1} = -c_{ws},$$

according to which equation (9) becomes:—

$$75\,\eta N/vqF = c_w + c_{ws} \quad . \quad . \quad . \quad . \quad . \quad (9a)$$

In this equation $75\,\eta N/vqF$ can be regarded as the total available drag coefficient, and, as c_w is the drag coefficient of the plane corresponding with the

speed v and the climbing angle θ, c_{ws} can be regarded as the drag coefficient available for climb, so that for the rate of climb, being equal to engine power available for climb divided by the weight of the aeroplane, we may write:—

$$w = c_{ws} q F v / G \text{ or } w = v c_{ws} / c_{ah} \quad . \quad . \quad . \quad . \quad . \quad (13)$$

Again, because $w = v \sin \theta$, it follows from (13) that

$$\sin \theta = c_{ws} / c_{ah},$$

so that this angle can be immediately read off from the figure.

Further, it follows from the formula, that the rate of climb will be maximum for

$$w = (v c_{ws} / c_{ah})_{max}.$$

With the aid of chosen values for v, curve (13) can be plotted. The maximum value of this curve gives the maximum rate of climb.

It is not generally appreciated that if the aeroplane is flying with engine "all out" a definite climbing angle corresponds with a definite speed v.

Von Mises,* for instance, writes the following when discussing a diagram representing the necessary engine power for overcoming the air resistance (Curve I) and the airscrew power available as a function of the speed:—

> "Genau genommen gilt also die Linie I nur für wagrechten Flug, und für jede von Null verschiedene Bahnneigung be müsste eigentlich eine *besondere Linie* gezeichnet werden.
>
> "Aber da wir uns im allgeneinen auf Bahnwinkel von weniger als 10° beschränken dürfen und der cos 10° noch 0.985 ist, so sieht man, dass der Fehler höchstens 1.5 v. H. ausmacht, dass also das ganze Büschel der Linien I in unsrer Zeichnung innerhalb einer Strichstärke von wenigen Zehnteln eines Millimeters enthalten sein müsste."†

Because it was obvious from the foregoing, that only one definite climbing angle corresponds with a definite speed, the right "Curve I" can also be fixed by one definite curve.

(d) Comparison Between the Method Generally Adopted and the New Method

When calculating the rates of climb according to the usual method, the necessary power for horizontal flight and the total available airscrew power are calculated for various flying speeds. The difference between both is regarded as the power available for climb, and from this the rate of climb is computed.

When trying to find out to what errors this method gives rise, we can remark that with the notation here used, and calling c_{wh} the drag coefficient of the aeroplane flying horizontally, it will follow from (1) that:—

$$w = 75\, \eta N / G - (c_{wh} / c_{ah})\, v \quad . \quad . \quad . \quad . \quad . \quad (14)$$

whereas this equation should read

$$w = 75\, \eta N / G - (c_w / c_{ah})\, v \quad . \quad . \quad . \quad . \quad . \quad (15)$$

Now, if Δ be the difference between two quantities, then:—

$$\Delta w = (v / c_{ah})\, (c_{wh} - c_w) \quad . \quad . \quad . \quad . \quad . \quad (16)$$

and also

$$\Delta \sin \theta = (1 / c_{ah})\, (c_{wh} - c_w) \quad . \quad . \quad . \quad . \quad . \quad (17)$$

It follows from (16) that, except at the ceiling altitude, where $c_w = c_{wh}$, (14) and (15) will always yield different results. The difference will increase

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* Prof. Dr. R. von Mises, "Fluglehre," Berlin, 1933, p. 330.

† As a matter of fact, "curve I" applies to horizontal flight only and for each climbing angle b differing from zero a separate curve should be drawn. However, because we are chiefly concerned with climbing angles of less than 10°, and cos 10° is still 0.985, it will be obvious that the maximum amount of the error will be 1.5 per cent., and that the whole set of "curves I" will be confined to an area of some tenth part of a millimetre wide.

the more c_w deviates from c_{wh}, which will generally be the case with great rates of climb.

(e) Calculation of the Rate of Climb of an Aeroplane at Sea Level According to Both Methods

In order to determine the amount of the differences in the results of both climbing speed calculations, several calculations were made.

As a first example an attack plane was chosen with no more than normal performance. A single-engined biplane with a weight of 1,500 kg., equipped with an air-cooled engine of 720 h.p. at 1,920 r.p.m. and a wing area of 20 m.² was proposed. The polar curve of the machine is shown in Fig. 2, and the engine curve in Fig. 3.

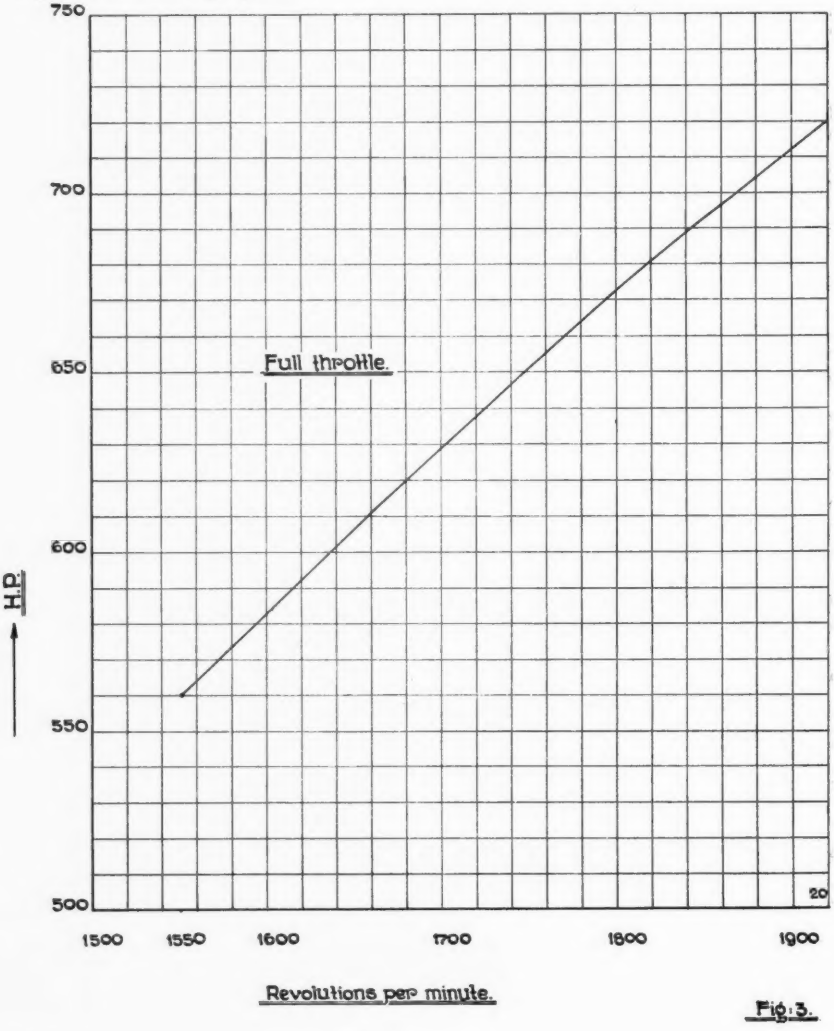

Fig. 3.

Suppose this machine is provided with an airscrew, the maximum efficiency of which is obtained at the maximum aeroplane speed, then after determination of the necessary airscrew diameter, which, as is done by Fokker for instance, can be computed with the aid of the following formula of Devillers.*

$$D = 1.04 \sqrt[4]{(10^8 N/n^2 v)}$$

and in accordance with the $\eta - v/nD$ curve from the " Handbook of Instructions for Airplane Designers," a maximum speed of the aeroplane of about 85 m./sec. is found at an airscrew efficiency of 80.4 per cent.

The differences between the rate of climb values when calculated according to both the usual and the new method amount to about 6 per cent. at certain flying speeds and to only about one per cent. at maximum rate of climb. It is understood, of course, that the results given by the new method are always higher than those obtained by the usual method.

As a matter of fact, these differences are not great in the vicinity of the maximum rate of climb; owing to the fact, however, that the amount of labour with both methods is about the same—which will be made clear by the following example—the exact method is to be preferred over the method which cannot yield other than approximate values only.

In the following case it was presumed that the machine was provided with an airscrew producing its maximum efficiency of 71.5 per cent. at a flying speed of 55 m./sec., an airscrew which might be obtained with close approximation by adjusting the blades of an airscrew designed for greater speed.

In Table I the available airscrew power has been calculated for the various speeds with the aid of the curves from the " Handbook of Instructions for Airplane Designers," which calculation is the same for both methods. In this table v_s indicates the speed for which the airscrew has been designed.

TABLE I.

CALCULATION OF AVAILABLE AIRSCREW POWER AT VARIOUS AEROPLANE SPEEDS.

	Height at sea level.					
Speed in m./sec.	30.4	35	40	45	50	55
v/v_s	0.553	0.636	0.727	0.818	0.909	1.000
n/n_{max} (acc. to graph)	0.875	0.886	0.903	0.930	0.961	1.000
n per min.	1680	1701	1734	1786	1845	1920
λ/λ_s	0.632	0.718	0.805	0.880	0.946	1.000
η/η_{max} (acc. to graph)	0.745	0.830	0.905	0.957	0.991	1.000
η	0.533	0.593	0.647	0.684	0.709	0.715
N in h.p. (acc. to engine curve)	620	630	644	666	691	720
ηN in h.p.	330	374	417	456	490	515

$\lambda = v/nD$ $\qquad$ $\eta_{max} = 0.715$

$\lambda_s = v_s/nD$ $\qquad$ $\eta_{max} = 1{,}920$ revs. p.m.

Further, in Table II the rates of climb have been calculated according to the usual method and in Table III according to the new method, whereas the results have been plotted graphically in Fig. 4.

The tables show that the differences in the results vary within range of flying speeds of 30.4 m./sec. (minimum flying speed when flying horizontally) to 55 m./sec. from about $7\frac{1}{2}$ per cent. to about $1\frac{1}{2}$ per cent.

The differences in the results for the maximum rate of climb values amount to about $1\frac{1}{2}$ per cent.; those of the maximum rate of climb per engine h.p. about 2 per cent.

* R. Devillers, " Le Moteur à Explosions," Tome II, p. 820.

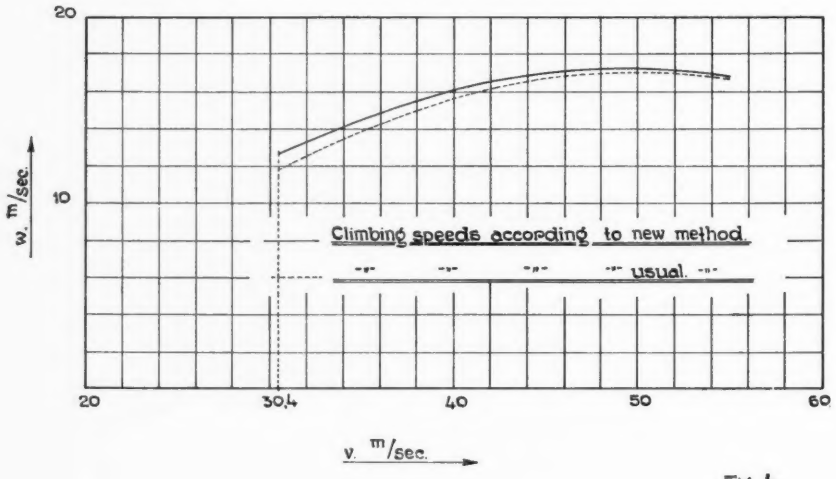

Fig 4.

TABLE II.

CALCULATION OF THE RATE OF CLIMB OF THE AEROPLANE ACCORDING TO THE USUAL METHOD.

	Height at sea level.					
Speed in m./sec.	30.4	35	40	45	50	55
ηN in h.p.	330	374	417	456	490	515
c_{ah}	1.298	0.980	0.750	0.593	0.480	0.397
c_{wh}	0.204	0.1285	0.0975	0.0804	0.0720	0.0662
N_{hor} h.p.	96	92	104	122	150	184
N_{cl} h.p.	234	282	313	334	340	331
w m./sec.	11.70	14.10	15.65	16.70	17.00	16.55

N_{hor} = power necessary for horizontal flight.
N_{cl} = power available for climbing.

TABLE III.

CALCULATION OF RATES OF CLIMB OF THE AEROPLANE ACCORDING TO THE NEW METHOD.

	Height at sea level.					
Speed in m./sec.	30.4	35	40	45	50	55
ηN in h.p.	330	374	417	456	490	515
$75\,\eta N/vqF$	0.705	0.523	0.391	0.300	0.235	0.186
c_{ah}	1.298	0.980	0.750	0.593	0.480	0.397
c_w (with the aid of circle and polar curve)...	0.166	0.1150	0.0900	0.0765	0.0695	0.0645
c_{ws}	0.539	0.408	0.301	0.2235	0.1655	0.1215
w m./sec.	12.60	14.55	16.05	16.95	17.25	16.85

In the next example the polar curve given in Fig. 2 was presumed to belong to a modern multi-engined aeroplane, the part of the fuselage between the wing being included in the wing area. The total weight of the aeroplane was taken at 3,000 kg. and the wing area at 40 m.^{2}.

Rates of climb were calculated for an assumed airscrew power varying between 600 and 1,200 h.p., and for flying speeds varying 30.4 to 60 m./sec. The results of these calculations have been plotted graphically in Fig. 5.

In Fig. 6 the results obtained for the powers of 1,000-1,100 and 1,200 h.p. were plotted in a somewhat different manner. In this figure the curves for the

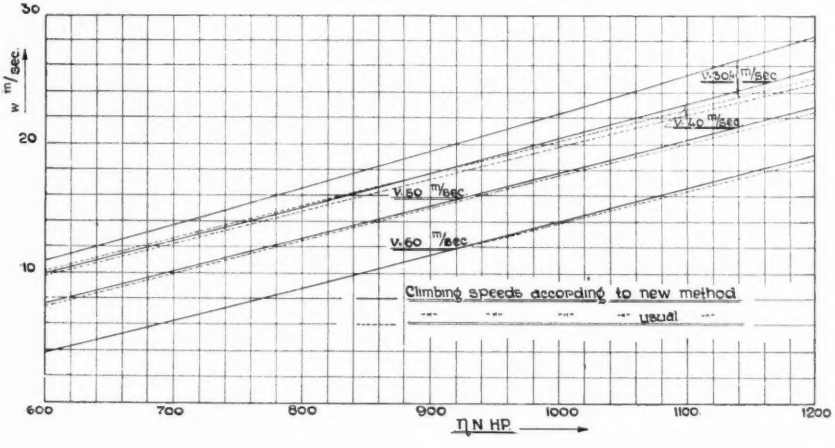

Fig. 5.

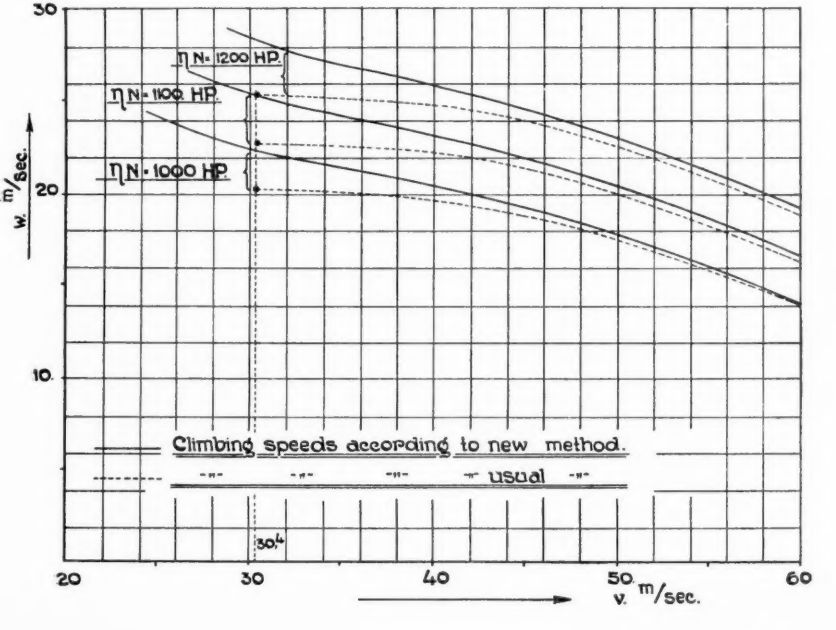

Fig 6.

rate of climb for a definite power have been continued till that speed at which the machine will climb vertically. This can be accomplished with the new method without any objections, because it does not matter whether the maximum c_{ah} value increases beyond the maximum c_a value of the polar curve. The only thing that matters is to obtain points of intersection of polar curve and circle.

With the usual method continuation of the rate of climb curves beneath the minimum horizontal speed of the machine is not possible. It is possible, for a last point, to determine the speed at which the machine will climb vertically by substituting for c_{wh} the value for which $c_{ah}=0$, but then one principally deviates from the method adopted, which will immediately show itself by irregular shape of the curves.

ABSTRACTS AND NOTICES
FROM THE
SCIENTIFIC AND TECHNICAL PRESS

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(Prepared by R.T.P.)

No. 32. DECEMBER, 1934

Aircraft Design, Performance, etc.

The "Herrera" Slide Rule for the Rapid Determination of Aeroplane Performance. (L'Aérophile, Vol. 42, No. 1, Jan., 1934, pp. 19-20.) (5.10/28701 France.)

The slide is rotatable and gives relations between surface, weight, power, rate of climb, cruising, landing and flying speed at various altitudes.

The relations are based on three typical polars characterised as excellent, average, and bad.

Possible Military Development of the Heinkel 70. (E. Vellay, L'Aéron., No. 177, Feb., 1934, pp. 35-36.) (5.10/28702 France.)

The high performance of the Heinkel 70 is partly due to clean design and small drag, partly to freedom from government restrictions. The machine, in the opinion of the author, is far ahead of contemporary design. Equipped and armed as a reconnaissance machine, it would give a better performance than any existing fighter. The great advance in performance suggests that the design of military aircraft is unduly handicapped by Government restrictions.

High Speed Air Transport. (A. Jona, Riv. Aeron., Vol. 10, No. 3, March, 1934, pp. 427-476.) (5.10/28703 Italy.)

A simplified theory of aeroplane dimensions is discussed. Statistics by various authors are quoted, and costs per ton mile are exhibited graphically as a function of a coefficient derived from the theory.

Extensive comparative statistics of performance are given for two single-engined and two three-engined machines. The author appears to favour higher speeds, on the ground that lower running costs per ton mile will compensate for higher initial costs.

Effect of Fillets on Wing-Body Interference. (A. L. Klein, Trans. A.S.M.E., Vol. 56, No. 1, Jan., 1934, pp. 1-10.) (5.11/28704 U.S.A.)

Two examples of filleting are compared by exploration of the wake behind the filleting by pitot tube. Graphical curves of lift, drag and moment as a function of incidence show comparisons of a low wing and a dropped wing without fillet, with three unsuccessful fillets and with a so-called optimum fillet. The last nearly restores the characteristics of the wing alone.

Further diagrams extend the measured results to various wing configurations and to high speeds.

In the discussion reference is made to buffeting and to the favourable effect of suitable filleting on this phenomenon.

Ten references.

Note on Interference. (E. Ower, Airc. Eng., Vol. 6, No. 62, April, 1934, pp. 93-96.) (5.11/5.32/28705 Great Britain.)

Divergent flow, in which the cross section of the tubes of flow increases down stream, becomes unstable and turbulent at flying speeds.

This principle is applied systematically to explain, qualitatively, a number of important points in flying practice. The best position of the wing in relation to the body, and of a nacelle in relation to the wing, are discussed in the light of test figures.

The airscrew wake introduces some modifications. "Buffeting" is considered briefly.

Ten references.

Effect of Compressibility on High Speed Flight. (J. Stack, J. Aer. Sci., Vol. 1, No. 1, Jan., 1934, pp. 40-43.) (5.13/28706 U.S.A.)

At very high speeds the compressibility of air increases the required power considerably. In a projected design for 550 m.p.h. flying speed the estimated effect of compressibility is an increase of 500 h.p. with a normal wing, and of 200 h.p. with a special wing.

Two references.

High Speed Flight. (M. Schrenk, Z.V.D.I., Vol. 78, No. 2, 13/1/34, pp. 39-47.) (5.13/28707 Germany.)

The development of high speed flying is more a question of aerodynamical design than increased engine power. Freedom from excrescences and smooth exterior of the whole aircraft is essential. The body must be of the minimum cross section, and great care has to be taken in the way body and wings are connected. For high speed work the low wing monoplane is favoured, with special filleting between body and wing.

Retractable landing gear is advantageous, and the use of flaps or wing slots to reduce landing speed allows of higher flying speeds.

Twenty-four references.

A Method of Comparing Performances of Commercial Aircraft. (M. Langley, J.R. Aer. Soc., Vol. 38, No. 282, June, 1934, pp. 477-480.) (5.14/28708 Great Britain.)

Diagrams show the relations between fixed load and disposable load. The latter is divided into fuel and pay load, on the assumption that the former increases and the latter decreases linearly with required range. The extreme range is shown as a limit with fuel only, and no pay load.

The effects of reducing drag, specific fuel consumption and other improvements are shown in diagrams of the same general nature. The method is a purely accounting one and no reference to details of design need be made.

Speed and Economics of Air Transport. (F. M. Green, J.R. Aer. Soc., Vol. 38, No. 282, June, 1934, pp. 449-476.) (5.14/28709 Great Britain.)

Analyses are given of overhead charges and running costs. Graphical analysis of flying weight shows the proportion of power plant and structure, fuel, passenger equipment and the residual true paying load, as functions of

flying speed from 100 m.p.h. to 170 m.p.h., the last item decreasing rapidly with flying speed. Numerical tables give a more detailed analysis.

The effect of design details on commercial performance is discussed. A lengthy discussion and reply thereto bring out the views of other designers and operators.

Impressions of a Tour on American Airways. (P. E. Koster and W. Schilo, Luftwissen, Vol. 1, No. 3, 15/3/34, pp. 66-76.) (5.14/28710 Germany.)

Notes on the organisation and operation of U.S.A. lines are prepared from observations and from information supplied personally. Operation includes navigation, engine development, fuel inspection, etc.

Sketches show noteworthy points—flaps, retractable carriages, wireless beacon installation. Statistics are briefly quoted. Photographs show the machine in which the tour was made and two examples of high speed air transport monoplanes with retractable carriages and no external bracing.

Safety in Aeronautical Design. (E. Teichmann and F. Michael, Autom. Tech. Zeit., Vol. 37, No. 2, 25/1/34, pp. 28-36.) (5.17/28711 Germany.)

In the present state of development fatigue stresses are the most dangerous. The aeroplane is a complicated structure with many possible modes of vibration and concomitant danger of resonance. Correlation of model experiments with full-scale work is required.

Twenty-four references.

The Lotz Method of Calculating Wing Characteristics. (B. S. Shenstone, J.R. Aer. Soc., Vol. 38, No. 281, May, 1934, pp. 432-444.) (5.20/28712 Great Britain.)

The characteristics of a wing with variable section are assumed to be summable from wing strip elements on the assumption that each element acts as a strip of an infinite wing.

A systematic scheme of Fourier analysis is developed for routine computations of distribution of lift, drag, pitching and rolling, and yawing characteristics.

A numerical example is worked out.

Five references.

"A.G." Wing with Variable Trim Incidence. (G. A. A. Guglielmetti, Riv. Aeron., Vol. 10, No. 4, April, 1934, pp. 18-30.) (5.206/28713 Italy.)

The wing is mounted on a single girder spar built up of steel tubes. From the illustration the cross section of the girder is a square of about 30 cm. side.

The four main tubes pass through a riveted plate rotatable on a central bearing parallel to the axis of the spar and controlled by a lever arm with a simple operating mechanism. Diagrams show the relative positions of the wing required to trim the body in line with the direction of motion through the air in level flight and in climb.

Details of construction are shown by photographs. Test performances are given in tables for different settings and show maintenance of performance and, in some cases, a sensible improvement in spite of the extra weight and the deep section imposed by the construction.

Strength of Aeroplane Wing Spars with Loads Varying in any One Bay. (J. Morris, J.R. Aer. Soc., Vol. 38, No. 282, June, 1934, pp. 515-518.) (5.25/28714 Great Britain.)

Berry's generalisation of the theorem of three moments is extended to the case of varying load in a bay.

Tests of Three Tapered Aerofoils Based on the N.A.C.A. 2200, N.A.C.A. M.6 and the Clark Y Sections. (R. F. Anderson, N.A.C.A. Tech. Note No. 487, Jan., 1934.) (5.25/28715 U.S.A.)

The aerofoils were tested in the variable density wind channel at a Reynolds number of approximately 3,100,000. The Clark Y aerofoil shows the best characteristics.

Three references.

Torsional Vibrations of a Cantilever Monoplane Wing. (A. Bellomo, L'Aerotecnica, Vol. 14, No. 1, Jan., 1934, pp. 27-39.) (5.26/28716 Italy.)

The assumption is made that the wing receives an impulsive distortion from a sudden gust or manœuvre. The differential equation of torsional vibration is formed, and three different cases are considered according to the relative position of the elastic axis. The differential equation is reduced to linear form by approximate assumptions and formal solutions are obtained.

The analysis is extended to three cases of variable torsional stiffness along the spar, and to a spar in several segments, with constant stiffness in each section, but with a jump of stiffness from section to section. In the first type the differential equation thus generalised is solved in Bessel functions of first and second kinds. In the second type the solution in each bay is simpler, but the passage from bay to bay requires a torsional analogue of Clapeyron's theorem of three moments.

Numerical examples are worked out.

Critical Velocities of Single-Spar Cantilever Wings. (C. Minelli, L'Aerotecnica, Vol. 14, No. 2, Feb., 1934, pp. 123-148.) (5.26/28717 Italy.)

The aerodynamic moment and its first derivatives with respect to incidence are assumed to be known. The differential equation is solved in terms of Bessel functions.

A second method is based on a further simplifying assumption which makes the differential equation linear and gives a solution in elementary functions.

Two numerical examples are worked out. Extensions of the method to torsional and dilatational vibration are developed in an appendix.

Four references.

Some Studies on the Flutter of Aerofoils and Propellers. (W. H. Taylor, Trans. A.S.M.E., Vol. 56, No. 2, Feb., 1934, pp. 57-64.) (5.26/5.63/28718 U.S.A.)

The author obtains an expression for the deflection of a cantilever flat bar of uniform section by air forces with elliptic load distribution. An approximate solution for the free torsional vibrations is deduced, and the problem of self-induced vibration is analysed.

An endeavour should be made to keep the period of lateral vibration of a wing or blade as far as possible from the self-induced period and consequent resonance.

Twenty references.

Investigation of "Zap" Wing Ailerons and Flaps. (R. Boname, Tech. Aéron., No. 131, 1934, pp. 4-31.) (5.30/28719 France.)

The Zap aileron is hinged above the trailing edge of the wing. The Zap flap is hinged on the lower surface at a distance of roughly one-third to one-sixth of the chord from the trailing edge. When closed it may overlap the trailing edge and increase the effective chord by roughly 10 per cent. When open (downwards) it acts as a spoiler.

An extensive series of tests was carried out with both flaps and ailerons in various positions. The optimum position of the aileron hinge was one-third aileron chord above the trailing edge. Numerous test results are shown graphically.

The mechanism of the flaps is shown in sketches and a photograph; their use increases the lift and gliding angle and decreases the landing speed.

The conclusions are not particularly favourable, but indicate possible advantages in special applications and in the hands of experienced pilots.

Adjustable Wing Flaps. (Luftwissen, Vol. 1, No. 2, 15/2/34, pp. 38-43.) (5.30/28720 Germany.)

A description is given of adjustable flaps applied to change the surface or form of wings.

The devices include slots and spoilers, and details are exhibited in 18 sketches.

Sixteen references.

Aerodynamic Moments of Various Control Surfaces. (P. Rebuffet, Pub. Sc. et Tech., No. 41, 1934.) (5.30/28721 France.)

Lateral control at low speed and high angle of incidence is of paramount importance. Amongst the devices described, the unsymmetrical increase of wing surface by means of a sliding auxiliary wing is of interest. In its normal position the auxiliary wing projects equally on either side of the wing tips of the main wing. The depth of the auxiliary wing is about one-third of the main wing chord, and the total surface about 10 per cent. of the main wing surface. The auxiliary wing slides parallel to the axis of the main wing, extreme position resulting in complete withdrawal into the wing at one side and maximum projection at the other.

Model experiments show that this method gives greater lateral control at large incidence than the normal aileron. The idea dates back to 1910, and is attractive if mechanical difficulties can be overcome.

Wing Fuselage Interference, Tail Buffeting and Air Flow about the Tail of a Low Wing Monoplane. (J. A. White and M. J. Hood, N.A.C.A. Report No. 482, 1934.) (5.32/28722 U.S.A.)

The experiments were carried out in the N.A.C.A. full-scale channel, the airflow round the machine being indicated by streamers. Tail buffeting is due to the eddying wake of the wing roots. Trials were made with different types of wing fuselage fillets, an N.A.C.A. cowling, a reflexed trailing edge next the fuselage, and auxiliary aerofoils in various combinations.

The best results were obtained by a combination of cowling and fillet, which reduced the tail oscillation to $\frac{1}{4}$ value and increased the all-round performance of the aeroplane. The reflexed trailing edge and the auxiliary aerofoil had little effect. Even without these modifications buffeting occurred only when the airscrew was not working.

Fourteen references.

Aircraft, Landing Gear, Hulls, etc.

Winter Landing Gear. (A. Ferrier, J.R. Aer. Soc., Vol. 38, No. 282, June, 1934, pp. 481-506.) (5.532/28723 Great Britain.)

Landing conditions are tabulated under five headings in respect of the state of the surface snow, and eight cross-headings in respect of the underlying ground —giving forty entries in all.

Photographs and sketches show various types of snow shoe and ski, alone or in combination with wheels or floats.

Pitching moments during landing are shown graphically, and recommendations are given for handling under different conditions.

Completed Tank Test of a Flying Boat Hull with a Pointed Step. (J. N. Shoemaker, N.A.C.A. Tech. Note No. 488, Feb., 1934.) (5.51/28724 U.S.A.)

The pointed step type of hull has less resistance at high speeds and there is a definite saving in take-off power.

Four references.

Investigation of Combined Ship's Stern and Rudder Fairing. (C. H. Rode, W.R.H., Vol. 15, No. 3, 1/2/34, pp. 30-31.) (5.51/28725 Germany.)

Contour lines show the stern form with and without fairing. Model tests were made with (*a*) stern and rudder unfaired, (*b*) rudder, only, faired to streamline form, (*c*) rudder and stern faired jointly.

Tables and curves of resistance as a function of speed show reductions in model resistance of 11 to 17 per cent.

Tank Tests of a Family of Flying Boat Hulls. (J. M. Shoemaker and J. B. Parkinson, N.A.C.A. Tech. Note No. 491, Feb., 1934.) (5.51/28726 U.S.A.)

Systematic changes were made in the hull lines, and characteristic curves are given for six model hulls.

The performance curves appear to be complicated functions of the variables, and the interpretation of the results in any precise manner is not possible. Further tests are suggested.

Five references.

Airscrews and Marine Screws

Measurement of Marine Screw Performance in the Hamburg Shipbuilding Research Society's Cavitation Tank. Part II. (H. Lerbs, W.R.H., Vol. 15, No. 6, 15/3/34, pp. 68-70.) (5.60/28727 Germany.)

In Part I the conditions for dynamical similitude were discussed, and it was shown that Froude's criterion is relatively unimportant when cavitation sets in, and a new parameter called the cavitation coefficient is introduced. (See Abst. 27017.)

In Part II conditions for dynamical similitude, with cavitation, are discussed in considerable detail and expressions are formed for a mean cavitation coefficient by integration. When Froude's criterion is satisfied, corresponding elements of the integrands are equal.

Numerical results are given for four different velocities of a model screw, and graphical representation shows the points lying close to a unicursal curve for low velocities but branching along four different curves at points corresponding to the critical cavitation velocities.

Five references.

Contrary-Turning Co-Axial Screws. (F. Rotundi, Engineering, Vol. 138, No. 3577, 3/8/34, p. 126. Summer Meeting of Institution of Naval Architects.) (5.610/28728 Great Britain.)

Full-scale trials on the training ship "Cristoforo Colombo," of 3,250 tons displacement with Diesel-electric drive, indicated a gain of 18 to 20 per cent. in propulsive efficiency. A similar disposition of airscrews has been made successfully on an Italian flying boat.

Increased Efficiency of Marine Screw with Guide Cowling. (F. Busmann, W.R.H., Vol. 15, No. 3, 1/2/34, pp. 29-30.) (5.644/28729 Germany.)

A sketch shows the annular cowl in section and end view. A converging channel is formed between the cowling and the tapered boss carrying the screw shaft. The section of the cowling wall is of thick aerofoil type. The entry length of the channel appears to be about four times the exit length.

Expressions are formed for efficiency under ideal flow in the manner of Froude and Rankine, and the efficiency—with and without cowl—is calculated and plotted, along with some other parameters, for a 15-knot steamer. The increase in ideal efficiency is from 26 to 32 per cent. at three knots, but only from 73 to 76 per cent. at 15 knots.

Various problems of design are mentioned, and efficiencies of 90 per cent. are considered possible in comparison with the 65 per cent. efficiency which represents common practice. No actual test figures are given.

Four references.

Marine Screws with Guide Cowlings. (L. Kort, W.R.H., Vol. 15, No. 4, 15/2/34, pp. 41-43.) (5.644/28730 Germany.)

As in the previous paper by Busmann (see Abstract 28729) the elementary hydrodynamical relations are worked out on the basis of the Froude-Rankine ideal actuator.

Photographs show two types of twin-screw drive with divergent guide channels formed by cowlings which reduce the emergent velocity. Diagrams show the velocity field with and without guide channels, from which the recuperation of energy may be computed.

In towing vessels a further advantage is obtained by diverting the two wakes to either side of the bows of the towed vessel, with corresponding reduction in the interference resistance.

Test results show noteworthy gains in effective thrust and efficiency.

Tug with Guide Cowling for Screw Propeller. (W.R.H., Vol. 15, No. 6, 15/3/34, pp. 73-74.) (5.644/28731 Germany.)

Section sketches show the general arrangement and the shape of the cowling.

Test results are given in tables and show increases in efficiency under representative conditions. (See Abstracts 28729 and 28730.)

Tests of Auxiliary (Hydroplane) Vanes. (J. B. Parkinson, N.A.C.A. Tech. Note No. 490, Feb., 1934.) (5.644/28732 U.S.A.)

The vanes are shown in a photograph as stub hydroplane surfaces forming a transverse extension of the planing area of a model flying boat hull. The effects were entirely unfavourable.

One reference.

Application of the Results of Systematic Propeller Tests to the Condition of Full-Size Airscrews. (K. Schaffran, Luftfahrtzeugbau und Luftfahrt, Vol. 2, No. 1, 1/1/34, pp. 7-8.) (5.612/28733 Germany.)

The tests were carried on in a water channel on models of airscrews, with the same blade form, but different pitches. The results are in satisfactory agreement with full-scale air tests.

Method of Calculating the Performance of Controllable Propellers with Sample Computations. (E. P. Hartmann, N.A.C.A. Tech. Note No. 484, Jan., 1934.) (5.658/28734 U.S.A.)

The gain in performance is mainly due to the increase of r.p.m. up to the maximum power available, especially with geared and supercharged engines. The take-off run is decreased and the rate of climb and ceiling are increased.

Six references.

The Ratier Variable Pitch Airscrew for Seaplanes. (L'Aérophile, Vol. 42, No. 1, Jan., 1934, p. 26.) (5.658/28735 France.)

There are two working pitches—one for take-off on the ground and one for altitude. The altitude pitch is set automatically when the air pressure falls below a fixed value. A partial balance between hub reaction, air reaction and inertia forces is obtained by inclining the blades from the perpendicular to the shaft and the required governing force is kept sufficiently small for operation under aneroid control.

Electrical Method of Measuring Small Vibrations and its Application to the Measurement of Vibration of Airscrew Blades. (J. Obata, S. Morita and Y. Yoshida, Aer. Res. Institute, Tokyo, Report No. 103 (Vol. 8, No. 7), Feb., 1934.) (5.660/28736 Japan.)

The body under examination forms part of a small air condenser, changes in the capacity of which produce change in the grid voltage of an amplifying set. The free transverse vibration of an airscrew was examined by clamping the boss rigidly and striking the blades at various points. The frequencies obtained are in general agreement with theory.

Five references.

Instruments

Stiffness of Helical Springs in a Direction Perpendicular to Spring Axis. (E. Rausch, Z.V.D.I., Vol. 78, No. 12, 24/3/34, pp. 388-389.) (6.102/28737 Germany.)

With certain simplifying assumptions the author establishes an equation for displacement under a force perpendicular to the spring axis. A useful relation is given with the axial extension under the same load. If under equal loads

δ_e = axial displacement,
δ_w = transverse displacement.

Then

$$\delta_w/\delta_e = 0.38\,[1 + 0.77\,(h/D)^2]$$

where

h = length of helical spring,
D = diameter of coil.

Five references.

Fluid Flow Indicator. (A. Fischer, Z.V.D.I., Vol. 78, No. 13, 31/3/34, p. 425.) (6.22/28738 Germany.)

The indicator consists of a hinged flap, in a cylindrical pipe, which is moved by the current and actuates a control rod. The control rod is enclosed in a cylindrical casing parallel to and connected with the pipe, with thin highly corrugated walls. One end of the cylinder is fixed, the other is moved axially by movements of the control rod in a manner analogous to a set of capsules in an aneroid. In this way the indications are transmitted externally without use of glands and stuffing box.

Torque Indicators. (K. Reuss, Ing. Arch., Vol. 5, No. 1, Feb., 1934, pp. 25-35.) (6.271/28739 Germany.)

A review is given of various devices. In particular a description is given of a device in which a fixed weight is suspended by a cord passing round a spiral cam, which gives effectively a variable lever arm.

In equilibrium the length of the lever arm is noted. The elementary geometry of the involute and the equiangular spiral is given.

Two references.

Aerodynamic Characteristics of Anemometer Cups. (M. J. Brevoort and M. T. Joyner, N.A.C.A. Tech. Note No. 489, Feb., 1934.) (6.40/28740 U.S.A.)

Authors' Abstract.—The static lift and drag forces on three hemispherical and two conical cups were measured over a range of angles of attack from 0° to 180° and a range of Reynolds numbers from very small up to 400,000. The problem of supporting the cup for measurement and the effect of turbulence were also studied. The results are compared with those of other investigators.

Five references.

Determination of Wind on Ships in Motion. (F. Musella, Riv. Aeron., Vol. 10, No. 1, Jan., 1934, pp. 75-82.) (6.40/28741 Italy.)

Photographs show details and mounting on ship board of a four-cup anemometer with a wind vane and pitot head.

Sketches show the indicating apparatus and divided circle for plotting the true wind from the relative wind and the ship's speed.

Wind Direction and Speed Indicator for the Yacht "Endeavour." (D. C. Gall, J. Sci. Inst., Vol. 11, No. 9, Sept., 1934, pp. 279-280.) (6.40/28742 Great Britain.)

Relative wind direction as determined by a mast head vane is repeated near the tiller by a rheostat electrical control. The relative wind speed is indicated by a hot wire instrument.

Stroboscopic Tachometer. (Engineering, Vol. 138, No. 3581, 31/8/34, p. 233.) (6.44/28743 Great Britain.)

The instrument weighs two pounds and has two speed ranges, 400 r.p.m. to 2,400 r.p.m. and 2,000 r.p.m. to 12,000 r.p.m. The latter range is obtained by observation through five slots.

Application of the Gyrostat to Speed Regulation. (O. Vocca, W.R.H., Vol. 15, No. 5, 1/3/34, pp. 53-55.) (6.44/28744 Germany.)

References are given by the Italian author to papers in the Italian technical Press. The elementary principle is based on the variable moment set up by a gyrostat in uniform rotation about its axis and in variable precession about an axis at right angles, the latter being produced by the coupling to the shaft of the main drive. In general, this device would compete with centrifugal governors.

The present article is restricted to a special application for maintaining effective synchronism (angular velocities equal or in constant ratio) between independent driving shafts.

Two co-axial gyros are kept in rotation in opposite directions by flexible drives from the two main shafts and the whole is kept in uniform rotation on an axis at right angles to the common axis of the gyros. Any departure from equal and opposite velocities produces precession of the housing controlled by spiral springs, and controls electrically a governing servo-motor. A high degree of sensitivity is obtained and in turn gives close regulation.

Nine references.

Oscillations of Automobiles and Their Determination. (E. Lehr, Z.V.D.I., Vol. 78, No. 10, 10/3/34, pp. 329-335.) (6.48/28745 Germany.)

The article describes how to determine experimentally the position of the C.G. and the principal moments of inertia of an automobile. Simple harmonic equations for the oscillation in a vertical plane are developed by replacing the car by a flat disc subjected to two double spring controls. The displacement of the springs is given by an equation of the type—

$$X_1 = A \cos(\omega_1 t) + B \cos(\omega_2 t).$$

The constants in the above equation can be determined with sufficient accuracy by studying the motion of the car when placed on eccentric rollers. The problem is complicated by damping and the author recommends that the experimental study of known successful types of springing must be carried out before the necessary control factors can be numerically estimated.

Eleven references.

Determination of the Speed of Sound by the Acoustic Interferometer. (E. Grossmann, Phys. Zeit., Vol. 35, No. 2, 15/1/34, pp. 83-88.) (6.48/28746 Germany.)

Direct measurement gives points of maximum and minimum intensity in the pressure field. If these are taken as nodes determining the simple wavelength, erratic values are obtained for the speed of sound.

A satisfactory reduction of these anomalies is given from consideration of the pressure field due to the interference of emitted and reflected sound waves. Suggestions that the speed of sound varies with frequency are shown to be superfluous and incorrect. Two examples of wave interference patterns are shown graphically.

Twelve references.

Speed of Air-Driven Rotors in Gyroscopic Instruments. (A. F. Spilhaus, J. Aer. Sci., Vol. 1, No. 1, Jan., 1934, pp. 44-46.) (6.52/28747 U.S.A.)

The various factors affecting rotor speeds are analysed. With a constant suction, the decreased external air pressure at altitude would cause an appreciable increase in rotor speed, which is only partially compensated by increased bearing friction at lower temperature. As a net result an appreciable increase in speed remains, which is more marked for the directional gyro than for the artificial horizon.

Five references.

Sensitive Bolometer Relay. (W. Jaekel, Z.V.D.I., Vol. 78, No. 5, 3/2/34, pp. 169-170.) (6.71/28748 Germany.)

The pointer of an electric current indicator moves across a narrow air stream issuing through a slot and alters its impingement on the bolometer wire. A movement of the pointer of the order of 15×10^{-4} mm. affects the cooling of the wire and energises the relay sufficiently to give a reading. The instrument has been used to measure the variation of plant growth with light intensity.

The air stream is produced by a membrane, vibrated electrically by means of a separate circuit. The relay is sufficiently sensitive to be operated direct by photo-electric cells of the transition layer type, without amplification.

Two references.

Heat Flow Meter for High Temperature. (E. Schmidt and J. Werneburg, Z.V.D.I., Vol. 78, No. 11, 17/3/34, pp. 343-346.) (6.72/28749 Germany.)

The heat flow meter consists of a strip of material in which are embedded thermocouples by which the temperature gradient can be measured. The strip is applied to the surface from which the flow is to be measured. The meter is calibrated by subjecting one face to a source of radiation and measuring by an optical pyrometer the heat transmitted and subsequently radiated at the other face. The heat given to the air by conduction is calculated from the temperature gradient near the surface, care being taken that the air is at rest.

For low temperatures the material of the strip is rubber. For high temperatures a strip or porcelain $6.5 \times 12 \times 0.9$ cm. is employed.

The meter measures heat flows of the order of 10,000 kcal/m²h at surface temperatures from 100°C. to 1,000°C.

Four references.

Theory of Heat Conduction in Fluids. (A. Kardos, F.G.I., Vol. 5, No. 1, Jan./Feb., 1934, pp. 14-24.) (6.72/28750 Germany.)

A critical review is given of previous attempts to form empirical, semi-empirical and rational relations between physical properties, thermal conductivity and viscosity. Some of these are moderately accurate within limited ranges. In particular the linear relation of the kinetic theory between viscosity and conductivity in ideal gases is shown by the example of carbonic oxide to be totally inapplicable to the liquid state.

The author propounds a new set of relations based on molecular properties, which give remarkably close numerical agreement with observations over a wide range of liquids and liquid solutions.

Thirty references.

Two Practical Applications of Heat Flow. (E. N. Fox, Phil. Mag., Vol. 18, No. 118, Aug., 1934, pp. 209-227.) (6.72/28751 Great Britain.)

Methods of solution are given for lagged surfaces with main flow of heat in one dimension and subsidiary cross flow.

The prohibitive complications of a full solution are avoided and approximations of various orders are given, according to the number of terms retained, with sufficient accuracy for practical purposes.

Two references.

Heat Transference in Fluids. (M. F. Treer, Phys. Zeit., Vol. 35, No. 6, 15/3/34, pp. 266-268.) (6.72/28752 Germany.)

A brief summary is given of Prandtl's attempt to analyse transfer of momentum and heat by eddies, on the basis of a " mean mixing path."

Experimental results given by four authors, from observations of flow round a cylinder, are plotted for comparison. An empirical formula obtained by Ulsamer contains a product of fractional powers of the Peclet number and the Reynolds number.

Seven references.

Radiation from Luminous and Non-Luminous Natural Gas Flames. (R. A. Sherman, Trans. A.S.M.E., Vol. 56, No. 3, March, 1934, pp. 177-192.) (6.72/28753 U.S.A.)

Natural gas flame may be either luminous or non-luminous. In the former the temperature is lower but the heat radiation is greater, with the additional advantages that the temperature is more uniform and the presence of free carbon is advantageous in many industrial processes, such as steel manufacture.

Fifteen references.

Apparatus for Measuring Thermal Conductivity of Metals up to 600°C. (M. S. van Dusen and S. M. Shelton, Bur. Stan. J. Res., Vol. 12, No. 4, April, 1934, pp. 429-440.) (6.72/28754 U.S.A.)

The comparative conductivities of the metal and of lead are measured. Determinations are made of the axial temperature gradient in two cylindrical bars soldered end to end, one end of the system being heated and the other end cooled. The cylindrical surface is protected from heat loss by a guard tube.

Data are given for various alloys widely used for heating elements and thermocouples.

Ten references.

A New Brake Meter for Cars. (Z.V.D.I., Vol. 78, No. 8, 24/2/34, p. 236.) (6.73/28755 Germany.)

Deceleration is measured by a pendulum decelerometer consisting of a U tube filled with mercury. The deflection is indicated by a liquid column superposed on the mercury with magnification and temperature compensation.

Two references.

Improvements in Acoustics of a Theatre. (W. Crone, H. Seiberth and J. Zenneck, Ann. d. Phys., Vol. 19, No. 3, Feb., 1934, pp. 299-304.) (6.95/28756 Germany.)

The reverberation time of a pistol fired in various parts of the theatre was recorded by oscillograph. The paths of reflection of the disturbing echoes were located and the reflecting areas damped by hangings of light stuff materials, with excellent effects.

Noise in Aircraft. (J. Denton, L'Aéron., No. 176, Jan., 1934, pp. 5-12.) (6.95/28757 France.)

A brief summary is given of physiological relations, with Fechner's approximate logarithmic increase of sensation, and the resulting scale of measurement in decibels.

A comprehensive tabular scheme gives the range of intensity of common sounds from 5 decibels up to 120 decibels, at which sensation becomes painful. Consideration is then given to the problem of aeroplane noises and illustrative figures are given for intensity of sound sources, exhaust, airscrew, engine, the transmission and absorption coefficients of various materials, and of the passengers themselves, with applications to the reduction of noise in the passenger cabin.

Aircraft Flight

Rolling and Yawing Moments Produced by Floating Wing-Tip Ailerons. (M. J. Bamber, N.A.C.A. Tech. Note No. 493, March, 1934.) (7.20/28758 U.S.A.)

A diagram shows the ailerons as continuations of the wing along the span, freely rotatable about the front spar.

Substantial increases in the coefficient of yawing and rolling moments opposing spin are shown graphically.

Nine references.

Effect of Trim Angle on Take-off Performance of a Flying Boat. (J. M. Shoemaker and J. R. Dawson, N.A.C.A. Tech. Note No. 486, Jan., 1934.) (7.30/28759 U.S.A.)

The effect of trim angle on water resistance was measured with N.A.C.A. models 11A, 16 and 22.

In the case of 11A, the same trim gave both minimum water resistance and minimum total (air and water) resistance.

The effect of trim on take-off and run is worked out in a numerical example. An instrument for determining trim on a seaplane under way is described.

Five references.

Stalling. (Wilbur Wright Lecture.) (B. M. Jones, J.R. Aer. Soc., Vol. 38, No. 285, Sept., 1934, pp. 753-770.) (7.70/28760 Great Britain.)

A descriptive account is given of the relation between air flow over the wing and the resulting air forces, near and above the stalling incidence.

Visual methods were advocated by Osborne Reynolds in 1884 for studying the flow of water and other fluids and have since been unduly neglected until

recent years. The use of visual methods is considered to be of the first importance, and a number of photographs are reproduced in illustration.

Reference is made to the considerable success of slots and other devices, but the lecturer is far from suggesting that the problem is solved, and puts forward his results only as a beginning of the necessary research.

Aerodynamics of the Wing Slot. (M. M. Munk, J. Aer. Sci., Vol. 1, No. 1, Jan., 1934, pp. 28-31.) (7.72/28761 U.S.A.)

The explanation of the action of the slotted wing, propounded by Prandtl and Betz, is unsatisfactory.

Two references.

Measurement of Upper Limits of Cloud and Fog. (R. Feige, Z. Instrum., Vol. 54, No. 1, Jan. 1934, pp. 23-26.) (7.80/28762 Germany.)

A modification of radio sounding apparatus for pilot balloons previously described in Z. Instrum., May 1932, p. 239, makes the registration of cloud and fog limits possible by measurements of light intensity. The sounding apparatus weighs about 5lb. and emits a continuous short wave beam, the exact wavelength depending on the photo-electric current registered on a milliammeter. A special transition layer (Sperrschicht) type of cell is employed and the motion of the milliammeter suspension system directly affects the capacity, and thus the wavelength, of the sending set.

Height signals are sent out by a momentary interruption of the emitted beam brought about by the expansion of a bourdon pressure gauge.

Two references.

Alighting of Flying Boats on Rough Sea or in the Dark. (W. Pacher, Flugsport, Vol. 26, No. 3, 7/2/34, pp. 51-54, and No. 4, 21/2/34, p. 73.) (7.80/28763 Germany.)

A brief descriptive account is given of familiar problems.

A sketch of a device for landing in the dark shows a rope passing through a loop attached to a shock absorber and trailing behind. On contact with the surface an impulse is communicated through the shock absorbed to the pilot and indicates a previously determined height above the surface.

Engines, Thermodynamics

The Influence of Pressure on the Spontaneous Ignition of Inflammable Gas/Air Mixtures. (D. T. A. Townend, L. L. Cohen and M. R. Mandlekar, Proc. Roy. Soc., Vol. 146, No. A.856, 1/8/34, pp. 113-129.) (8.13/28765 Great Britain.)

In this, the third article of a series, experiments are described with hexane and isobutane/air mixtures. The results are in general agreement with the previous experiments using butane and pentane, and demonstrate the great effect of pressure in lowering the ignition temperature.

At certain critical pressures between 1 and 3 atmospheres a relatively small increase of pressure may produce a lowering of ignition temperature of the order of 200°C. For non-critical pressures the effect is much less, *e.g.*, doubling the pressure from 5 to 10 atmospheres will not generally lower the ignition temperature by more than 5°C.

The effect of lead dope is to increase the ignition temperature throughout. The actual rise is again very much magnified at the critical pressure. The authors put forward the view that the lowering of the ignition temperature by increase of pressure is due to the survival of certain unstable intermediate products which are formed in the precombustion period.

The ignition temperatures observed by the authors are accompanied by time lags varying from 1 to 30 seconds and have no direct application to engine conditions with a lag of less than 0.005 sec.

Eleven references.

Flame Temperatures in Methane-Air Mixtures. (W. T. David and J. Jordan, Phil. Mag., Vol. 18, No. 118, Aug., 1934, pp. 228-236.) (8.13/28764 Great Britain.)

The fuel mixtures are exploded in a spherical bomb with central ignition and the flame temperature measured by means of a fine platinum resistance wire near the centre. The reading of the thermometer rises quickly after ignition to a value which remains constant for a time and is followed by a further rise.

The first maximum gives the true flame temperature, the subsequent rise being due to compression. The temperatures obtained in this way are several hundred degrees lower than those obtained by alternative methods, *e.g.*, sodium line reversal.

The authors put forward a physical argument indicating that the latter method gives temperatures in excess of the true equilibrium value.

Eleven references.

The Specific Heat of Gases at High Temperatures. (W. T. David and A. Smeeton Leah, Phil. Mag., Vol. 18, No. 118, Aug., 1934, pp. 307-321.) (8.13/28766 Great Britain.)

The specific heats calculated by Nernst and Wohl for H_2 N_2 OO CO_2 and H_2O, in accordance with the Planck-Einstein relations, give better agreement with explosion experiments than the generally accepted value, but lead to improbably high engine thermal efficiencies.

It is suggested that the molecules of gases in engines have not time to reach equipartition of energy in the various modes of vibration, and act accordingly as molecules of simpler type with fewer modes of vibration and lower specific heat.

Twenty-two references.

Phenomena of Ionisation in the Adiabatic Expansion of Gases. (P. Benzi, L'Aerotecnica, Vol. 14, No. 3, March, 1934, pp. 267-281.) (8.15/28767 Italy.)

As a preliminary to the study of the ionisation of a fuel mixture in an engine, the author has investigated the behaviour of moist air when undergoing compression and expansion. It appears that ionisation depends on the presence of fog, and that a conductor exposed to the fog will be charged positively or negatively according to the temperature of the conductor.

Eighteen references.

A Critical Test for the Purity of Gases. (M. Shepherd, Bur. Stan. J. Res., Vol. 12, No. 2, Feb., 1934, pp. 185-191.) (8.15/28768 U.S.A.)

One approximately isothermic distillation yields a small initial distillate, a middle distillate containing the bulk of the gas and a small final residue. The vapour pressures of these three fractions are compared and indicate impurities of higher and lower boiling points than that of the approximately pure substance.

Two references.

Engines, Design and Performance

The Bertin Turbo-Compressor. (Engineering, Vol. 137, No. 3569, 8/6/34, pp. 643-645.) (8.235/28769 Great Britain.)

Two discs rotate in opposite directions with equal angular velocities. The blades are approximately equi-angular spirals, and their leading edges seen in

side elevation form an orthogonal system of curves. In side elevation the channels or ducts formed by opposite blade pairs narrow rapidly from hub to periphery and impose a compression on the delivery stream.

The mean rotational velocity is reduced to zero by symmetry, and the eddy energy is relatively small. The diagrams of performance show delivery against r.p.m. with both discs rotating in the same direction, with one stationary, and with both rotating in opposite directions.

The deliveries for the same mean angular speed of rotating parts are in the ratios 1 : 4 : 16 against the pressure 16 inches of water.

A Comparison of Several Methods of Measuring Ignition Lag in a Compression Ignition Engine. (J. A. Spanogle, N.A.C.A. Tech. Note No. 485, Jan., 1934.) (8.28/28770 U.S.A.)

A stroborama gave the beginning of fuel injection. The beginning of ignition was estimated by three methods:—

(*a*) Beginning of first pressure rise on indicator diagram.
(*b*) Point of diagram corresponding to the combustion of 3 per cent. of the injected fuel.
(*c*) First appearance of glow in combustion chamber observed through a quartz window.

The first method was found to give the most consistent results. The last method gave considerably greater lags, interpreted as showing considerable pre-combustion before visible flame. In spark-ignition engines the last method gives consistent results.

Six references.

Researches Carried Out in the Physical Laboratory of the French Air Ministry. (L'Aéron., No. 178 (Bulletin), March, 1934, p. 29.) (8.28/28771 France.)

Voltage and current curves of ignition systems were studied by cathode ray oscillograph. The character of the discharges is as important as the maximum voltages.

New Steam Plants for Locomotion. (K. Imfeld and R. Roosen, Z.V.D.I., Vol. 78, No. 3, 20/1/34, pp. 65-74.) (8.294/28772 Germany.)

Messrs. Henschel and Son, Ltd., the well-known German locomotive builders, are developing a new type of steam power plant suitable for lorries, rail cars, and motor boats. Steam at approximately 100 atmospheres and 500°C. is generated in a steel tube, one end of which is exposed to the action of a blow-pipe flame, whilst the feed water enters the other end. The blow-pipe is fed with compressed air and can deal with a great range of common liquid fuels. By means of relays, the temperature and pressure of the steam is kept automatically constant by regulating the heat supply and the amount of feed water.

The steam is employed in a compound engine of orthodox design working directly on the driving wheels. The exhaust is condensed at atmospheric pressure, the necessary cooling air being supplied by an auxiliary high speed fan.

It is stated that the plant competes successfully with Diesel-engined installations.

Two references and forty-four illustrations.

Engines, Design and Strength of Components

Possibilities and Load Characteristics of a New Journal Bearing with the Dimensions of a Roller Bearing. (A. Riebe, Autom. Tech. Zeit., Vol. 37, No. 5, 10/3/34, pp. 133-138.) (8.31/28773 Germany.)

Constructional details are given of narrow journal bearings using " carobronze " interposed between steel liners.

The bearings may be cylindrical or of double curvature, and the lubrication may be by wick or pressure. It appears that loads and speeds may be imposed comparable with those for roller bearings of similar dimensions.

The Design of Journal Bearings and Their Lubrication. (E. Meier, Autom. Tech. Zeit., Vol. 37, No. 5, 10/3/34, pp. 138-142.) (8.31/28774 Germany.)

Bearing troubles in Diesel engines applied to transport work are classified under five heads:—

(1) Excessive crankshaft deflection.
(2) Insufficient bearing dimensions.
(3) Unsuitable backing of bearing and bad adhesions of bearing metal.
(4) Poor manufacture.
(5) Faulty lubrication.

An investigation was carried out with a simple form of impact machine developed for testing adhesion. Good results were obtained with a lead bronze backing and a cast-on layer of graphite lead, 0.3 mm. thick, as actual bearing surface. The bearings should be machine-cast and there should be no oil grooves on the part of the surface subjected to maximum pressures.

Reliability of Pistons and Rings in Large Air-Cooled Engines. (A. Fussenhauser, Luftwissen, Vol. 1, No. 3, 15/3/34, pp. 62-65.) (8.32/28775 Germany.)

Air-cooled engines work at a higher temperature level than water-cooled. The temperature of the barrel near the head is critical, since any marked excess of 180° causes the lubricating oil to distil and the pressure seal between piston and barrel breaks down. This in its turn causes a rapid rise in piston temperature, which already may be in the neighbourhood of 350°C. in the centre of the crown, compared with 250°C. in the case of water-cooled engines.

Light alloy cylinders fitted with special " Niresist " cast iron liners can be run with finer piston clearances, since the expansion of this special cast iron is of the same order as that of al. alloy.

Thirty-seven references.

The Alumilite Process for Pistons. (Comm. Motor, 13/4/34, p. 292.) (8.32/28776 Great Britain.)

It is standard practice in America to cover the surface of aluminium alloys with a film of oxide of varying degrees of hardness, depending on requirements, and to impregnate the film with oil or graphite. The life of piston grooves is increased by this treatment.

The process can also be applied to light alloy parts previously chromium plated. A high reflecting coefficient and a non-tarnishing finish are obtained.

Investigation of Vibration Periods by Electro-Magnetic Analogy. (L. Kettenacker, F.G.I., Vol. 5, No. 2, March-April, 1934, pp. 67-71.) (8.36/28777 Germany.)

A sketch shows an elastic shaft with discrete flywheel masses and the analogous electrical circuit with discrete reactions and capacities. The form of the applicable linear differential equations is the same, and comparison of the constant coefficients gives the electro-magnetic mechanical analogy.

A diagram of connections shows the exciting circuit, " analogy " circuit and recording circuit, the latter producing a resonance curve as the exciting frequency is varied through the appropriate range. By choice of corresponding scales, the resonance diagram can be read directly as torsional oscillations.

A numerical example is given with data for a mechanical system and for the corresponding electro-magnetic system.

Seventeen references.

Cast Crankshafts. (Autom. Tech. Zeit., Vol. 37, No. 1, 10/1/34, pp. 11-12.) (8.36/28778 Germany.)

Certain kinds of Ni-cast iron have found application in cast crankshafts and camshafts. Apart from low cost, the absence of changes in cross-section due to notches and keyways avoids the concomitant peak stresses. The cast shaft may therefore be stronger than a steel shaft, provided the deflections are kept within limits by choice of dimensions. The high internal damping of cast shafts promotes smooth operation.

Two references.

Roller Bearings and Their Employment in Automobile Construction. (Dipl. Ing. Jurgensmeyer, Autom. Tech. Zeit., Vol. 37, No. 5, 10/3/34, pp. 143-148.) (8.37/28779 Germany.)

The noise of bearings is largely a question of clearance. The author discusses the design of various mountings for minimum play. The problem is difficult in the case of conical roller bearings, since the cones assume different positions when mounted under static friction and when running under vibration. The transition from one position to the other may take several hours under load.

Effect of Speed, Load and Clearance on Seizing Temperature. (N.P.L. Report for 1933, p. 158.) (8.38/28780 Great Britain.)

The seizing temperatures vary directly as the speed and inversely as the load, and there is an optimum clearance depending on the viscosity of the oil.

By repeated seizure or approach to seizure a skin of molecular dimensions forms on the metal which is resistant to fracture and is maintained intact at speeds below that at which fluid lubrication is possible. The bearing then apparently improves.

The Running-in of New Engines. (E. Mahle, D.M.Z., Vol. 11, No. 1, Jan., 1934, pp. 12-16.) (8.38/28781 Germany.)

Tapered piston rings reduce the running-in period considerably. They are standard fittings in several American cars.

Four references.

Engines, Cowling

Air-Cooled Engine Cowling. (J. D. North, Airc. Eng., Vol. 6, No. 62, April, 1934, pp. 100-110; also J.R. Aer. Soc., Vol. 38, No. 283, July, 1934, pp. 566-612.) (8.426/28783 Great Britain.)

An account is given of the development of cowlings in comparison (somewhat controversial) with the Townend ring. The design problem involves the cooling of the cylinder head as well as the reduction of head resistance.

A selection of experimental results obtained in this country and U.S.A. is discussed in considerable detail from the viewpoint of the designer.

Eleven references.

The Cowling of Radial Engines. (R. B. Beisel, A. L. MacClain and F. M. Thomas, Airc. Eng., Vol. 6, No. 64, June, 1934, pp. 151-158, and No. 65, July, 1934, pp. 197-200; also J.R. Aer. Soc., No. 283, July, 1934, pp. 613-650.) (8.426/28784 Great Britain.)

The development of radial air-cooled engine cowlings in U.S.A. has proceeded in parallel with the development of the Townend ring in this country. The fundamental objects are to reduce head resistance and to maintain adequate cooling of the cylinders.

Measurements were made with a N.A.C.A. cowling and a disc baffle plate, cut away to clear the projecting cylinders and fins by about $\frac{1}{4}$in., in a plane slightly aft of the cylinder axes. The air flow is controlled by regulating the air outlet slot in the skirt of the cowling. The test figures show that the reduced air flow, directed closely over the cylinders, gives reduced drag and maintains adequate cooling. More uniform cooling is obtained, especially with two bank radial engines, and the whole or part of the air flow may be supplied by a fan.

A selection of the work done is presented in detail and shows that haphazard methods are unlikely to give satisfactory results.

Rules are laid down to guide the designer.

Three references.

Engines, Lubricants and Lubrication

The Ageing of Castor Oil. (M. Roy. Pub. Sc. et Tech., No. 40, 1934.) (8.540/28785 France.)

Prolonged heating of castor oil at temperatures in the neighbourhood of 100°C. causes "ageing" involving the following physical and chemical changes:—

(1) Considerable increases in density, viscosity, refractive index and molecular weight.

(2) Slight increase in surface tension.

(3) Marked increase in acidity, with decrease in the iodine value.

The changes in the properties of the oil finally lead to complete jellification. The jelly is insoluble in the usual castor oil solvents, but completely soluble in paraffin oil at 100°C.

The author describes a neat method depending on observation of surface tension for recording the acidity and thence determining the amount of "ageing." Steel containers accelerate the ageing notably. The presence of various so-called anti-oxidants had but slight effect on the changes.

Lubricating Quality (Oiliness) of Oils and Solid Greases. (S. Erk, Z.V.D.I., Vol. 78, No. 12, 24/3/34, pp. 389-390.) (8.540/28786 Germany.)

A testing machine for "oiliness," designed by Thoma, and used in the Munich Technical High School, is here described. It consists of two cylinders in contact under a known force, the axes and force being mutually orthogonal. The cylinders are rotated by external drives and the friction of the contact is measured directly. Although totally immersed in oil, the readings of the machine are not determined by the viscosity of the oil, since the type of contact renders a continuous oil film impossible.

The test conditions are supposed to represent partial seizure in a bearing. It is possible to mix oil to produce a series of constant viscosities, but giving very different friction measurements in the machine, *e.g.*, the addition of rape seed oil to a mineral oil may lower the measured friction by 50 per cent. The reduction in measured friction of the original oil by mixing is not related to the measured friction of the added oil, *e.g.*, glycerine shows a lower measured friction than olive oil, but its addition to a mineral oil is much less effective.

Tests were also carried out on the effect of the material of the cylinders on the friction. White metal with high lead content and lead bronzes produced the least measured friction. The relative order of merit of various bearing metals depended on the nature of the oil.

The experiments are being extended to include certain fats and greases. There appears to be no connection between the lubricating efficiency of a grease and its consistency.

New Methods and Machines for Testing Lubricating Oils. (O. P. van Steewen, W.R.H., Vol. 15, No. 5, 1/3/34, pp. 60-62.) (8.540/28787 Germany.)

The " Spindel " testing machine built by the M.A.N. is described. A rotating disc either dips in the oil to be tested or has its external surface lubricated by a drip feed. A small plane test block is held against the circumference of the disc with an adjustable pressure and the resultant friction is measured by torque reaction of a box which surrounds the disc and to which the arm carrying the test block is attached. The temperatures of the test piece and of the rotating disc are controlled and recorded under varying loads and speeds up to the breakdown, from fluid lubrication to practically solid friction. The amount of wear taking place on the block is readily measured and correlated with the nature of the metal and oil.

On account of the simple shape of the block and its method of support, subsidiary forces (such as may exist in normal bearings due to expansion or unsymmetrical application of the load) are obviated and the machine works with great consistency.

Engines, Fuels

Petrol from Coal. (Airc. Eng., Vol. 6, No. 64, June, 1934, p. 171.) (8.600/28788 Great Britain.)

A brief descriptive technical account is given of the processes employed.

Ethyl, etc. (F. R. Banks, J.R. Aer. Soc., Vol. 38, No. 280, April, 1934, pp. 309-372.) (8.645/28789 Great Britain.)

The undoubted effectiveness of tetraethyl lead in suppressing detonation has countervailing disadvantages. Even small concentration in a normal engine produces burning and corrosion of the exhaust valve and deposits on the sparking plug, making starting difficult. These undesirable effects may be mitigated for concentrations of the order of 4 c.c.s per gallon.

Ni-cr. steels of the austenitic type are recommended both for the exhaust valve and seat. To prevent corrosion when the engine is stored, specially treated oils are injected into the cylinders and valve gears. Much can be done by attention to the construction of the sparking plug and its working temperature.

The increasing use of dopes requires an accepted method of rating fuels. At the present there are considerable discrepancies in the findings of various laboratories.

Eleven references.

Engine Knock. (L. Withrow and S. N. Rassweiler, Autom. Eng., Vol. 24, No. 322, Aug., 1934, pp. 281-284.) (8.645/28790 Great Britain.)

Simultaneous records of the pressure rise and flame travel in an engine running under power show that under knocking conditions the gas has a vibrating motion. The frequency of the ripples in the expansion curve of the indicator diagram corresponds closely with the period of variations in flame brightness, both being of the order of 3,000 cycles per sec.

Thirteen references.

The Miscibility of Petrol and Some of its Components with Alcohols of Various Strengths. (W. R. Ormandy, T. W. Pond and W. R. Davies, Inst. Pet. Tech., 1934—I.A.E. Research and Standardisation Committee No. 7131, May, 1934.) (8.649/28791 Great Britain.)

Of the petrol constituents, heptane mixes worst with alcohol and benzene best. Of the alcohols, isopropyl alcohol generally mixes best with petrol constituents. A blend of ethyl alcohol and isobutyl alcohol with petrol gave a water

tolerance far above the mean values and generally greater than for either alcohol unmixed.

A.M. Detachable Connection for Petrol Pipes. (L'Aéron., No. 178, March, 1934, p. 63.) (8.684/28792 France.)

A detachable joint is required when fuel tanks are jettisoned. The joint described is of the bayonet locking type. The union is maintained by a collar against a strong spring and is disengaged by rotation of the collar. The spring forces the ends apart and seals the fixed end.

Engines, Injection and Exhaust Systems

Effect of Viscosity on Fuel Leakage between Lapped Plungers and Sleeves and on the Discharge from a Pump Injection System. (A. N. Rothrock and E. T. Marsh, N.A.C.A. Report No. 477, 1934.) (8.705/28793 U.S.A.)

The principal factor in determining leakage is the clearance between plunger and liner. By suitable design, the leakage can be made independent of the pressure. Provided the injection pump is supplied with fuel under pressure, large changes of viscosity are permissible without affecting the rate of fuel discharge of the pump.

Eight references.

Valve Seat Wear. (C. G. Williams, Autom. Eng., Vol. 24, No. 320, June, 1934, pp. 219-221, and No. 321, July, 1934, pp. 246-248; also Airc. Eng., Vol. 6, No. 63, May, 1934, pp. 141-144.) (8.725/28795 Great Britain.)

Experiments were carried out on a special test ring supplied by the A.E.C. It consists of a water-cooled cylinder head with overhead valves, the exhaust valve being operated in the normal manner, whilst the inlet valve remains shut. The head is subjected to the radiant heat of a gas furnace, arrangements being made for the products of combustion to pass out through the exhaust port of the cylinder. The wear experiments were supplemented with engine trials on two 500 c.c. J.A.P. engines and one 3.64 litre Thornycroft.

Exhaust valve temperature is of the order of the temperature of the exhaust gases measured immediately behind the valve. The seat temperature is usually about half the valve temperature. All temperatures depend on operating conditions such as engine speed, mixture strength and spark setting. Other factors are engine design, degrees of cooling, length of valve guide and materials of guide, valve and seat. It appears that valve materials and tappet clearance are the principal factors in determining wear.

Development in Valve Seats in Automobile Engines. (J. C. Fritz, Autom. Tech. Zeit., Vol. 37, No. 1, 10/1/34, pp. 12-14.) (8.725/28796 Germany.)

Valve seats made of Monel metal or steel are shrunk into the cylinder casting by warming the casting to a temperature depending on the thermal expansion of the material (warm water may be sufficient) and cooling the insert in liquid air. Subsequent stelliting of the surface is often useful.

Engines, Gears

The Pitting of Gear Wheels. (M. Ulrich, Z.V.D.I., Vol. 78, No. 2, 13/1/34, pp. 53-55.) (8.761/28797 Germany.)

The pitting of gears due to fatigue of material under varying loads is avoided by accurate workmanship and suitable hardening processes, such as case hardening or cyanide treatment.

Four references.

Principles Underlying Automatic Automobile Gears. (H. v. Thungen, Z.V.D.I., Vol. 78, No. 10, 10/3/34, pp. 309-315.) (8.761/28798 Germany.)

Modern gear boxes are of four types which may be arranged in a scale of decreasing claims on the driver's attention :—

(*a*) Synchronised.
(*b*) Pre-selector.
(*c*) Semi-automatic.
(*d*) Fully automatic.

In fully automatic gears the governor actuating the change should respond both to speed and torque. It is hoped that a reliable automatic gear may soon become available, though not so far commercially successful.

Armament

The Madsen Machine Gun. (R. de l'Armée de l'Air, No. 54, Jan., 1934, pp. 87-91.) (9.11/28799 France.)

The heavy calibre gun (20 m./m.) weighs 55 kg. and fires continuously 125 rounds per minute. For short periods the rate can be trebled. Explosive shells can be used, the fuse being sufficiently sensitive to detonate on perforation of a canvas panel.

The light gun (11.35 m./m.) will fire short bursts at the rate of approximately 1,000 shots per minute. The aircraft model weighs 7 kg.

The guns are of Danish construction and are covered by numerous patents.

Patents Concerning the Launching of Torpedoes from Aircraft. (R. de l'Armée de l'Air, No. 56, March, 1934, pp. 352-358.) (9.2/28800 France.)

Three patents, dated Nov., 1928, were taken out by the French Ministry of Marine.

Torpedoes have to be launched from aircraft at about 30 feet above the water and meet the surface nearly horizontally with a considerable shock.

The first patent describes a method of giving a slight pitching rotation to the torpedo by a delayed release acting behind the C.G. Meeting the water at an angle reduces the impact, but the torpedo may ricochet or dive if the incidence is too small or too large.

The second patent covers the correction of diving by a small buoy attached near the nose by means of a rolled up length of rubber cable. On immersion the buoy is released and before parting from its cable exerts the necessary lift on the nose.

The last patent proposes to correct ricochetting by flattening the nose of the torpedo immediately behind the percussion horns.

Air Torpedoes or Bombs. (" Vultur," Riv. Aeron., Vol. 10, No. 3, March, 1934, pp. 391-398.) (9.3/28801 Italy.)

A brief descriptive technical discussion is given of relative cost and weight and personnel involved in relation to the effective amount of explosive.

The argument appears to favour bombs, but the conclusion is left open.

Practice Bomb. (R. de l'Armée de l'Air, No. 55, Feb., 1934, pp. 229-230.) (9.31/28802 France.)

The subject matter of French patent No. 745599 is the visibility of impact on soft ground and in vegetation. The bomb contains a rocket in addition to the principal charge. On impact the destruction of the principal charge emits a smoke cloud. The rocket is fitted with a delay fuse and forms a second smoke cloud about 15 feet above the point of impact.

Sprinkler Installation for Air Defence. (H. Huebner, Z.V.D.I., Vol. 78, No. 7, 17/2/34, p. 216.) (9.4/28803 Germany.)

Reference is made to incendiary bombs with magnesium alloy case and thermit filling, developng a temperature of 2,000°C. and producing an incandescent mass of metal, with its own internal supply of oxygen, and to phosphorus bombs which need only be of a few kilograms weight to penetrate the roofs of dwelling houses, each fragment of phosphorus becoming a potential centre of incendiary fire.

An experiment was carried out with a sprinkler automatically set in action by high temperature. Two photographs show first, a one-kg. thermit bomb starting a fire in a pile of shavings; second, the room after extinction of the fire in 20 seconds by the sprinkler. The formation of explosive gas by dissociation of water at high temperature was investigated and found to be negligible.

One reference.

Aerial Defence of England. (A. A. U. Fischetti, Riv. Aeron., Vol. 10, No. 1, Jan., 1934, pp. 23-31.) (9.77/28804 Italy.)

A brief analysis is given of the problem of defending London against air attack.

A map is reproduced showing zones of A.A.C. defence, lines of defence by aircraft and positions of defending squadrons, with figures of number of aircraft and A.A.C. guns available.

Materials, Characteristics, Defects and Treatment

Tensile Strength of Steels at Low Temperatures. (G. Gruschka, Forschungsheft No. 364, Jan./Feb., 1934.) (10.100/28805 Germany.)

The elastic limit, tensile strength, extension and contraction were measured for a series of steels over the range 20°C. to −200°C. Decrease of temperature generally increased the first two properties but reduced the extension and contraction to a small fraction. The results have important application in the design of liquid gas containers.

Modern Researches on Mechanical Strength and Their Influence on Practical Design. Review of papers read at Materials Congress, Essen. (E. Lehr, Z.V.D.I., Vol. 78, No. 13, 31/3/34, pp. 395-401.) (10.104/28806 Germany.)

In general the fatigue limits of alloy steels are more sensitive to abrupt change of cross section, notches, keyways, etc., than carbon steels. For this reason M.A.N. construct the piston rods of two-stroke engines exclusively in carbon steel, protected by a liner from any corrosive effect of the cooling water. If at all possible shoulders should be avoided and wheels and pinions fitted on plain shafts.

In designing crankshafts useful comparative results are given by the elementary theory of the forces on the pin and web, using the combined gas and inertia forces. The true stresses are appreciably higher, but from experience with 150,000 shafts one firm is confident that the maximum stresses are proportionate to the values calculated in this simple manner.

Fifteen references.

Research on the Fatigue of Steels. (R. Cazand, Pub. Sc. et Tech., No. 39, 1934.) (10.104/28807 France.)

A test piece was subjected to alternating stresses on a modified Wohler machine, the load being applied at the overhung and rotating end. Special attention was given to the shape. Linear relations were found between the elastic and ultimate strength limits and the fatigue limits with large variations in the slopes of the straight line graphs.

For the 95 steel samples tested the factor varies from 0.19 to 0.66. The authors trace a connection between the factor and the composition, heat treatment and micro-structure of the steel. Generally speaking, tempering at temperature of the order of 600°C. increases the fatigue limits, although it may diminish the elastic limit and tensile strength.

Sixty-five references.

Velocity of Corrosion. (U. R. Evans and R. B. Mears, Proc. Roy. Soc., Vol. 146, No. A.856, 1/8/34, pp. 153-165.) (10.125/10.262/28808 Great Britain.)

Consideration is given both to the electro-chemical reaction and to concomitant mechanical effects, such as the setting up of convection currents by local changes in density and by the sinking of corrosion products, the formation of protective films and the effect of cracks in metals. A number of corrosion time graphs illustrates the arguments.

Thirty-two references.

Prevention of Intercrystalline Corrosion in Rustless Austenitic Chrome Nickel Steel. (Z.V.D.I., Vol. 78, No. 8, 24/2/34, p. 252.) (10.125/28809 Germany.)

Intercrystalline corrosion is due to the formation of carbides with high Cr. content. It is prevented by the addition of titanium and reduction of the carbon content below 0.04 per cent.

One reference.

The Stability of Rails. (F. Raab, Z.V.D.I., Vol. 78, No. 13, 31/3/34, pp. 405-410.) (10.140/28810 Germany.)

The end clearances between rail butts to allow for thermal expansion are detrimental to high speeds. Rail lengths may be welded at the butt joints to form a continuous beam at temperatures above the normal so that the continuous welded rail is in tension at mean temperatures. This may be safely done by using a steel with high crushing limit and by strengthening the holding down bolts.

The stability of the arrangement is discussed and experiments show that the continuous welded rail will not deform at temperatures up to 100°C.

Five references.

Measurements of Stresses in Spiral Springs. (F. Thiersch, F.G.I., Vol. 5, No. 2, March/April, 1934, pp. 53-59.) (10.164/28811 Germany.)

The elastic equations are briefly discussed. By introducing approximations at an early stage a simplified expression is obtained which otherwise can be deduced from the general expression.

Experimental values of the strain are compared with calculated values and show discrepancies which generally are within permissible limits. The effects of overstrain and of fatigue are discussed. Practical formulæ for designs are given.

Fourteen references.

Mechanical Properties of Brass. (F. Ostermann, Z. Metallk., Vol. 26, No. 2, Feb., 1934, pp. 40-44.) (10.200/28812 Germany.)

Mechanical properties of a number of brasses are exhibited in twenty-three diagrams, according to composition, cold working, heat treatment, etc.

Seventeen references.

Influence of Temperature on Elastic Properties of Cast Aluminium Alloys. (M. Schwartz and A. Evers, Z. Metallk., Vol. 26, No. 2, Feb., 1934, pp. 37-39.) (10.231/28813 Germany.)

The observed residual extension of a German alloy is plotted against stress for five temperatures from 20° to 250°. Similar curves for a self-hardening

U.S.A. alloy show much higher conservation of mechanical properties in the same temperature range. The results are tabulated numerically and are discussed in some detail.

Three references.

Influence of Heavy Metals in Aluminium Alloys. (P. Rontgen and W. Koch, Z. Metallk., Vol. 26, No. 1, Jan., 1934, pp. 9-18.) (10.231/28814 Germany.)

A brief survey is given of technical papers. The structure, constitution, mechanical properties and hardening are investigated in five groups according to the content of Cu Mo Ni Cr Co Fe Mn Mg Zn and Ag.

A mass of data is given in tables and 41 microphotographs are reproduced. The Brinell hardness and tensile strength of lautal are shown graphically as functions of the proportions of chromium after treatment and after annealing. Comparative data are given in a table for three other alloys.

The best alloy is specified on the basis of these data as containing 4 per cent. Cu and 1 per cent. Mo.

Magnesium Alloys for Aeronautical Purposes. (L. Aitchison, J.R. Aer. Soc., Vol. 38, No. 281, May, 1934, pp. 382-412.) (10.232/28815 Great Britain.)

Mechanical properties of magnesium alloyed in various proportions with copper, zinc, cadmium, aluminium and silicon, singly or in groups, are given in Tables 1-8. Mechanical properties after casting, rolling, extruding (with and without heat treatment) and forging are given in Tables 9-14.

Fatigue tests and tensile tests at high temperatures (up to 350°C.) are given in Tables 15 and 16. Examples of petrol tanks and airscrews are shown in photographs.

Tables 20-24 show selected corrosion tests in comparison with aluminium. Fatigue and corrosion, especially in cast magnesium alloys, appear to be the outstanding uncertainties.

A vigorous discussion follows.

Prospects of Beryllium as a Material of Aeroplane Construction. (F. Vogel, Luftwissen, Vol. 1, No. 3, 15/3/34, pp. 77-78.) (10.234/28816 Germany.)

The specific gravity of beryllium is 1.7 compared with aluminium 2.7 and steel 7.9. Pioneer work was done in U.S.A. and a brief account is given of subsequent work in Germany. Siemens and Halske have produced 2,000 kilograms in a year at a cost of 400 R.M. per kilogram (£20 gold).

Cheaper methods of production are anticipated.

Magnetostrictive Alloys with Low Temperature Coefficients of Frequency. (J. M. Ide, Proc. Inst. Rad. Eng., Vol. 22, No. 2, Feb., 1934, pp. 177-190.) (10.240/28817 U.S.A.)

Author's Abstract.—Thirty-four magnetic alloys of iron, nickel, chromium and cobalt were prepared and studied in order to find compositions which have substantially zero temperature coefficient of frequency of longitudinal vibration. Rods of these alloys were made to be used as secondary frequency standards, to stabilise the frequency of magnetostriction oscillators. The same alloys would be valuable for tuning forks.

It was found that the temperature coefficient of frequency is a function of composition, heat treatment, temperature and magnetisation. Seven compositions were found which gave temperature coefficients of the order of one cycle in a million per degree Centigrade, when properly heat-treated and magnetised. Five of these showed large dynamic magnetostriction and gave good frequency stabilisation when used with a magnetostriction oscillator.

Four references.

Growth of Surface Layer of Oxide on Metals. (A. Steinheil, Ann. d. Phys., Vol. 19, No. 5, March, 1934, pp. 465-483.) (10.262/28818 Germany.)

The oxide layers were examined by electron diffraction patterns. The initial rate of growth of aluminium oxide films was abnormally large and thereafter settled down to the growth indicated by diffusion theory. The structure of anhydrous aluminium oxide films was identified as cubic crystals of $Al_2 O_3$.

Other results are established of immediate scientific interest and possibly with future technical applications.

Sixteen references.

Corrosion of Screws in Aluminium Alloys. (H. Bauermeister, Z. Metallk., Vol. 26, No. 2, Feb., 1934, pp. 34-37.) (10.262/28819 Germany.)

Instrument construction almost invariably involves the use of screws and when aluminium alloys are used the tendency of brass and steel screws to corrosion requires serious consideration. Aluminium screws soon seize and break off when force is used.

A systematic series of trials was made with 24 screws of KSS alloy, silumin (cast), phosphor bronze, brass and iron. In some cases before exposure to corrosion the screws were oiled or greased. The results are tabulated in four classes according to the difficulty of unscrewing after exposure to corroding influences.

1. Easy to unscrew.
2. Medium easy.
3. Difficult.
4. Immovable.

Individual cases are influenced largely by protective greasing. Practical conclusions are given for designers.

Sea-Water Resisting Alloy, "Corrix." (Autom. Tech. Zeit., Vol. 37, No. 5, 10/3/34, pp. 149-150.) (10.262/28820 Germany.)

A new ternary Cu-Al-Fe alloy, density 7.6, has been developed under the trade name of "Corrix." The castings have a tensile strength of the order of 40 tons per sq. in., the extension being over 20 per cent. A simple heat treatment gives a Brinell hardness of over 200.

The alloy is extremely resistant to corrosion and is being widely employed in motor car and seaplane fittings.

Chromium Coating of Surfaces. (G. Eisner, Z.V.D.I., Vol. 78, No. 13, 31/3/34, pp. 415-421.) (10.264/28821 Germany.)

The best current density for the electrolytic deposition of chromium is about ten times that for nickel. Chromium can be deposited directly on nickel or copper, but with other metals it is in general necessary to deposit first a thin film of copper, nickel or other suitable carrier on which in turn the Cr. is deposited.

With suitable precautions as to cleanliness, current density, bath temperature, purity of chemicals, etc., excellent results are now obtainable.

Seven references.

Behaviour of Various Building Materials in a Fire and the Effect of Protective Treatment of Wood. (A. Schulze, Z.V.D.I., Vol. 78, No. 1, 6/1/34, pp. 23-28.) (10.420/28822 Germany.)

Various types of brick walls were tested, one surface being kept at approximately 1,000°C. by an oil fire in an experimental chamber.

The properties of so-called fire resisting glass and protective treatments for wood were investigated. No chemical treatment will prevent the ultimate destruction of wood, but the spread of the fire can be greatly retarded. Fire resisting glass also yields to high temperature.

In reference to the effects of air attacks, further full-scale experiments are recommended.

Two references.

Fire Proofing of Wood. (Paquin, Z.V.D.I., Vol. 78, No. 2, 13/1/34, p. 60.) (10.420/28823 Germany.)

The German chemical combine (I.G.F.I.) has produced a fire proofing dope called " Intravan," suitable for plywood, as it does not affect the mechanical properties of the glue. It can be sprayed without the need of gas masks for the operators.

One reference.

Apparatus for Determining the Surface Finish of Wood. (E. Kratz, Z.V.D.I., Vol. 78, No. 6, 10/2/34, pp. 202-203.) (10.420/28824 Germany.)

A flanged glass tube is pressed on the surface under investigation. The tube is evacuated by means of a water jet pump to a predetermined pressure. The mass of air leaking into the tube across the flange is determined by venturi air meter and gives a measure of the surface finish of the wood.

Formulæ are given connecting the leakage with the effective area of surface grooves in the wood, both for viscous and for turbulent flow.

Two references.

Seasoning of Timber—Optimum Conditions. (H. Voigt and E. Ramspeck, Z.V.D.I., Vol. 78, No. 8, 24/2/34, pp. 245-247.) (10.420/28825 Germany.)

A high drying temperature accelerates the seasoning and improves the quality of the final product. Warping and internal stresses produced by unequal drying set a limit which depends on the type of wood, the coefficients of diffusion, conductivity and the mechanical properties.

From the experiments the best drying temperature and duration of the seasoning process are given for beech, pine and fir.

Ten references.

Impregnation of Timber Against Fire. (E. Dietze, Z.V.D.I., Vol. 78, No. 12, 24/3/34, p. 386.) (10.420/28826 Germany.)

Tests are described with a new impregnating material manufactured by I. G. Farben Industries under a trade name.

Two full size models of ship cabins similarly furnished were constructed using treated and untreated wood fittings. A fire was started with petrol. In the treated cabin the fire went out in 12 minutes and the highest temperature reached was 600°C., and a considerable portion of the woodwork survived the fire. In the untreated cabin a temperature of 1,000°C. was reached after 15 minutes and all the woodwork was consumed.

Aeroplane Dopes. (J. J. A. Gilmore, Airc. Eng., Vol. 6, No. 64, June, 1934, pp. 161-164.) (10.600/28827 Great Britain.)

A review is given of the development of cellulose acetate and cellulose nitrate varnishes (nitrocellulose appears to be a misnomer) by the addition of different solvents and pigments to produce the desired combination of qualities—tautening, flexibility, stability under light, etc. Two examples of specifications are given.

Successive advances have led to proprietary varnishes applicable under ordinary conditions of atmospheric temperature and humidity, of which the composition is more or less a trade secret.

An outline of test requirements and methods is given.

Dry Film Glueing in Plywood Manufacture. (R. Sorenson, Trans. A.S.M.E., Vol. 56, No. 1, Jan., 1934, pp. 37-48.) (10.660/28828 U.S.A.)

It has been conclusively established that phenolic resin is the best glue for plywood. It is waterproof, resists atmospheric action and has high shear strength.

Thirteen references.

Measurement of Internal Damping in Engineering Materials. (W. Klein, Ing. Arch., Vol. 5, No. 1, Feb., 1934, pp. 1-6.) (10.90/28829 Germany.)

A sketch shows a cylindrical iron bar on which an electro-magnet imposes longitudinal vibrations. The vibrations of the free end were observed electromagnetically by variation of voltage in an induction coil, measured by a valve voltmeter.

The elastic equations are written down in polar co-ordinates and the numerical solution is plotted graphically. Measured points lie closely along the calculated curve. (See, however, Abstract 26146, 1933.)

Eight references.

Testing Apparatus and Methods of Testing

Experimental Verification of the Theory of Wind Tunnel Boundary Interference. (T. Theodorsen and A. Silverstein, N.A.C.A. Report No. 478, 1934.) (11.10/28830 U.S.A.)

The boundary correction factor of the N.A.C.A. full-scale channel is in satisfactory agreement with flight tests. The theory may be regarded as established and the calculated values are given for all conventional types of channel.

Contribution to the Investigation of Open Throat Wind Channels. (L. Lazzarino, L'Aerotecnica, Vol. 14, No. 3, March, 1934, pp. 245-254.) (11.10/28831 Italy.)

The author develops the results of Tollmien on turbulent diffusion. Jet fluctuations are due to variation of the diameter in the free section, which is increased by the indrawing of the surrounding air.

The pressure is divided into two parts, for which formal expressions are obtained, computed, tabulated and plotted graphically.

Two references.

The Use of the Wind Tunnel in Connection with Aircraft Design Problems. (T. v. Karman and C. B. Millikan, Trans. A.S.M.E., Vol. 56, No. 3, March, 1934, pp. 151-166.) (11.10/28832 U.S.A.)

The corrections applied to model results in a 10ft. channel with steady flow are sufficiently accurate to render unnecessary for general work very large or variable density channels with their prohibitive costs.

Attention is given to the stability of the boundary layer and its effect on the maximum lift coefficient. The large effect of turbulence on the lift coefficient is intimately connected with its effect on the position of transition from laminar flow to turbulence in the boundary layer and the position of the branching point at which the flow is diverted from the surface. The well known effect of turbulence on the characteristic drag of a sphere is due to similar causes.

Thirteen references, twenty-five illustrations.

Superaerodynamics. (A. F. Zahm, J. Frank. Inst., Vol. 217, No. 2, Feb., 1934, pp. 153-166.) (11.10/28833 U.S.A.)

Experiments in high vacuum wind channels would provide data on the effect of a relatively long mean path of the particles of the fluid. The case of an

infinitely long mean free path was considered by Newton. The subject is of interest in the study of the stratosphere (*e.g.*, in reference to resistance of projectiles, rockets and shooting stars).

Five references.

New N.P.L. Wind Tunnels. (A. R. Collar, Airc. Eng., Vol. 6, No. 64, June, 1934, pp. 165-170.) (11.10/28834 Great Britain.)

A technical account is given of the principles applied to the design of two open jet wind channels with closed return circuit replacing one closed channel with open return circuit. The saving in size and power is substantial.

The application of guide vanes at right angle bends has quite superseded other methods and should have an important influence in the general design of ventilating air shafts.

The use of screw vanes in front of the airscrew imparts a preliminary rotation to the air which may be adjusted to give zero mean axial rotation behind the disc. The angular speed of the screw is decreased and the distribution of velocity is improved everywhere, but no appreciable gain in power is obtained.

Much information of interest is given and drawings of general arrangements and of some details are reproduced.

Air Force Measurements on Bodies Moving Through Still Air. (R. H. Smith and J. Van H. Whipple, J. Aer. Sci., Vol. 1, No. 1, Jan., 1934, pp. 21-27.) (11.12/28835 U.S.A.)

The tangential forces at the surface of a body with a certain critical fineness ratio are sensitive to channel disturbances for all attitudes, whereas the normal forces are sensitive only near the stalling attitude.

A coasting apparatus is described which enables the forces on a model in still air to be determined. Calibration runs with flat discs held normal to the wind show satisfactory agreement with other experiments. Further tests are to follow.

Nine references.

Lift on Flat Plate in Bounded Stream. (S. Tomotika, Aer. Res. Institute, Tokyo, Reports Nos. 100 (Vol. 8, No. 4) and 101 (Vol. 8, No. 5), Jan., 1934.) (11.16/28836 Japan.)

The first report deals with a stream bounded by an infinite plane, the second with a stream bounded by two parallel walls. The same types of conformal transformation are used, in which finally the plate becomes the outer of two concentric circles, the boundary the inner. Elliptic integrals are used, with Weierstrass, sigma, zeeta and theeta functions. Numerical values are calculated and tabulated for different values of incidence and distance from the wall.

The lift is always increased, in particular by two-thirds at incidence 9° and distance three-quarters chord from the plane.

In report No. 101 with the same types of transformation the plate again becomes the outer of two concentric circles and the boundary the inner. The methods follow closely Rosenhead's analysis (see Abstract 22144). An oversight in Rosenhead's conclusions is pointed out at some length, the latter's results holding only for the important mid-channel position, for which alone numerical values were calculated.

The necessary generalisation for any distance is carried out in the report under review and the corresponding numerical values are tabulated. In every position there is an increase in lift.

When one boundary is removed to infinity the results of the report 100 are reproduced, as should be the case.

Theory of Frahm Anti-Rolling Tanks. (O. Foppl, Jng. Arch., Vol. 5, No. 1, Feb., 1934, pp. 35-42.) (11.20/28837 Germany.)

The problem is stated and illustrated by diagrams. Simplifying approximations reduce the differential equation of motion to linear form, which is solved in the usual way.

Four references.

Airships

Russian Aircraft. (R. de l'Armée de l'Air, No. 54, Jan., 1934, pp. 68-72.) (12.30/28838 France.)

The U.R.S.S. are turning out a number of small semi-rigid airships, the Italian constructor Nobile (of Arctic fame) acting as consultant. These ships are fitted with Titan engines apparently imported from France.

L.Z. 129 Commercial Airship. (Luftwissen, Vol. 1, No. 1, 15/1/34, pp. 13-14.) (12.10/28839 Germany.)

The capacity of the ship is 190,000 m.^{3}, almost double that of L.Z. 127. Both H_2 and H_e are used, the former for manœuvring purposes.

Four Diesel engines each of 1,200 h.p. max. drive the airscrews. Two small auxiliary engines driving electrical generators are completely isolated from the rest of the ship. The whole of the power plant is controlled by the chief engineer from one control room.

Wireless

New Type of Thyratron Relay. (G. Babat, Proc. Inst. Rad. Eng., Vol. 22, No. 3, March, 1934, pp. 314-323.) (13.2/28840 U.S.A.)

A new form of Thyratron relay circuit is described. It is capable of delivering a direct current without interruption from an alternating current supply. An application of this circuit to photo-electric work is described.

Short and Ultra Short Electric Waves. (A. Scheibe, Phys. Zeit., Vol. 35, No. 5, 1/3/34, pp. 206-215.) (13.31/28842 Germany.)

A brief review is given of the development of radio transmission. The increase in the number of transmitting stations has required a wider range of wave lengths, first in the direction of increasing length up to 18 km., now in the direction of short wave lengths.

The elementary theory is stated and illustrated by diagrams.

Twenty-five references.

Optimum Operating Conditions for Class C Amplifiers. (W. L. Everitt, Proc. Inst. Rad. Eng., Vol. 22, No. 2, Feb., 1934, pp. 152-176.) (13.32/28843 U.S.A.)

Author's Abstract.—A theoretical analysis of the plate efficiency and output of a triode operating as a class C amplifier is made. A linear amplifier with any desired operating angle is described. Three cases in the operation of a triode as a class C amplifier are analysed for the load impedance which will give maximum output.

It is shown that for a given tube, plate voltage and plate loss, there is a definite value of load impedance, C bias, and grid excitation voltage, which will give maximum output. A rapid method of determining these optimum operating conditions is shown and checked experimentally.

Rectangular Short Wave Frame Aerial for Reception and Transmission. (L. S. Palmer and D. Taylor, Proc. Inst. Rad. Eng., Vol. 22, No. 1, Jan., 1934, pp. 93-114.) (13.4/28844 U.S.A.)

In a previous paper (see Abstract 25108) the parameters frame height/wave length and frame width/wave length were correlated with current received and observed critical values were accounted for on physical grounds.

The physical theory is now generalised for receiving and transmitting frames and it is shown that maximum current does not correspond to maximum radiation.

One reference.

Series-Phase Aerials. Marconi's Wireless Telegraph Co., Ltd. (Engineering, Vol. 138, No. 3581, 31/8/34, p. 235.) (13.4/28845 Great Britain.)

Inclined elements arranged in parallel produce a marked concentration of intensity along a parallel direction. The front mast should not be less than half the wave length. The rear mast need only be a few metres from the ground.

A four-element aerial shows gains of 12 to 15 decibels over a half-wave aerial. Radial spacing round a centre allows of selection of the direction of the beam without prohibitive size or cost.

A Compensated Thermionic Electrometer. (K. G. Compton and H. E. Haring, Bell Tele. B-780, 1933.) (13.5/28846 U.S.A.)

A method is described of compensating a single vacuum tube electrometer for variations in battery voltage by inserting an adjustable resistance in the negative lead of the filament. The compensated circuit shows satisfactory stability in comparison with two matched tubes. Uncompensated and compensated calibration records are shown graphically.

Without compensation a decrease of about 5 micro-amperes in the galvanometer circuit was produced by a decrease of 1 per cent. in the operative voltage. With the compensation resistance adjusted to the circuit, the change in the current was insensible. Currents of 10^{-17} amperes can be detected and measured.

Five references.

New Cathode Ray Oscillograph. (F. K. Harris, Bur. Stan. J. Res., Vol. 12, No. 1, Jan., 1934, pp. 87-102.) (13.5/28847 U.S.A.)

The cathode source of the stream of electrons is an oxide coated filament surrounded by a metal shield kept at the same potential with a plane surface, facing the anode and pierced by a small central hole. The anode is a cone truncated at the vertex which faces the cathode.

The focussing effect of this arrangement produces an intense beam of electrons passing through the hole in the anode along the axis of the tube. A focussing coil brings the stream to a focus at the screen. The stream passes through a diaphragm (which sharpens the focus), between the deflection plates and through a grid before striking the fluorescent screen. Between the grid and the screen a second acceleration is applied.

The brightness of the fluorescent spot is a function of the impressed voltage between the grid and the screen, increasing rapidly up to about 5 kv., beyond which it falls off asymptotically to a steady value. The intensified spot gives oscillograms which can be photographed directly.

Applied to the study of hysteresis loss in dielectrics, the instrument gives readings and brings out a relation between abnormal increase in hysteresis and approaching failure of the material which should throw light on the process of breakdown of dielectrics.

Ten references.

The Iconoscope (Image Viewer)—Television. (V. K. Zworykin, Proc. Inst. Rad. Eng., Vol. 22, No. 1, Jan., 1934, pp. 16-32.) (13.7/28848 U.S.A.)

Minute globules of silver deposited on a thin mica sheet are separated by the latter from a conducting plate and the whole is closed in a vacuum tube. The globules are photo-sensitive and emit electrons when exposed to light, the positive charge thus produced being proportional to intensity and to time of exposure, until saturation is approached.

The scene to be transmitted is focussed in the plate and produces a charge distribution on the mosaic, proportional to light intensity. The plate is scanned by an electron beam focussed to a small area (covering about twenty of the photo-electric elements) which discharges the elements successively at such a rate that the mosaic as a whole does not become saturated photo-electrically. Thus a rapidly variable discharge current from the common plate is superposed on a slowly varying current due to changes in the total illumination of the scene. These variations are amplified for transmission.

In scanning methods the time of illumination and the photo-electric charges are reciprocal to the number of picture elements, *e.g.*, with 70,000 elements the illumination is 1/70,000 that of continuous exposure. Hence, in principle, the charge produced by continuous exposure of the mosaic should be greater in this ratio. Actually 10 per cent. of the increase has been realised, giving a gain factor of several thousands.

Details of development and application are given with characteristic curves, diagrams of connection, and photographs of the complete apparatus.

Four references.

Television. (V. K. Zworykin, J. Frank. Inst., Vol. 217, No. 1, Jan., 1934, pp. 1-37.) (13.7/28849 U.S.A.)

Both translation and reproduction of the image are accomplished by special cathode ray tubes. The image is projected on a photo sensitised mosaic and transformed into a train of electrical impulses by means of a scanning beam of electrons, the electrical " memory " of the mosaic aiding the definition considerably. The impulses are transformed back into variations of light intensity at the receiving end by the bombardment of a fluorescent screen by a second beam of electrons. The synchronised signals are transmitted with the television signals.

Photographs of images obtained by this method show a high order of merit.

Six references.

Velocity Modulation Television System. (L. H. Bedford and O. S. Pickle, Inst. Elec. Engrs., Vol. 75, No. 451, July, 1934, pp. 63-92.) (13.7/28850 Great Britain.)

The principle underlying the method is to vary the brightness by varying the velocity of the scanning ray inversely as the brightness of the object scanned. It is restricted, therefore, to scanning a film behind which is a photo cell system, the output from which controls the speed of the scanning spot.

At the receiving end a ray of uniform brightness traverses a screen with velocity proportional to that of the scanning ray and reproduces the original object on obvious principles of physiological sight perception. The cathode ray oscillographs are the only instruments capable of such rapid variations in speed.

The details are necessarily complicated and are fully described. A mathematical theory is given. A discussion follows.

Thirty-four references.

Measurement of Photographic Densities by Photo-Electric Methods. (S. A. Boutry, Pub. Sc. et Tech., No. 38, 1934.) (13.7/28851 France.)

The measurement of photographic density is intimately connected with thickness of emulsion and optical quality of the glass plate. Details are given of the photo-electric circuits, in which a copper oxide rectifyer was used to ensure stability.

One hundred and sixteen references.

Optical Measurement of the Type of Motion of a Piezo-Electric Oscillator in Fluids. (E. Hiedemann and H. R. Asbach, Phys. Zeit., Vol. 35, No. 1, 1/1/34, pp. 26-28.) (13.81/28852 Germany.)

A fluid transmitting high frequency sound acts as an optical grid. Three photographs are reproduced showing interference effects under impulses from a piezo-electric oscillator.

A direct measure of the distribution of energy in the whole fluid or in a thin layer is obtained by adjustment of the thickness of fluid illuminated. Comparison with Rayleigh's theory showed agreement to a first approximation only, which can be improved by modifications of the apparatus.

Nine references.

Supersonic Dispersion in Gases. (E. G. Richardson, Proc. Roy. Soc., Vol. 146, No. A.856, 1/8/34, pp. 56-71.) (13.81/28853 Great Britain.)

The propagation through various gases of supersonic waves emitted by piezo-electrically maintained quartz crystal is examined experimentally. The anomalous dispersion observed may be due to one or more of three factors:—

(*a*) Lag in the transfer of energy between the different degrees of freedom of the molecule.
(*b*) Resonant or selective absorption.
(*c*) Abnormal viscosity under high frequency.

No definite conclusions are reached as to the relative importance of these factors, nor is it definitely known what happens to the absorbed energy. Some evidence is adduced to show that the latter is largely scattered by the gas.

Twenty-five references.

Photography

Objective Visibility Meter. (L. Bergmann, Phys. Zeit., Vol. 35, No. 5, 1/3/34, pp. 177-179.) (14.30/28854 Germany.)

Reference is made to Wigan's apparatus, which depends on the insertion of clouded glasses between eye and object until visibility just vanishes.

In the present apparatus a selenium transition layer photo-cell is employed with sensitivity distributed over the visible spectrum in approximate proportion to that of the eye. A beam of light interrupted by a stroboscopic shutter is partly transmitted through a glass plate at 45° to a distant mirror and returned to a selenium cell, partly reflected on to a similar selenium cell. The cells thus receive rays which have passed over a long and short air path. The short ray is stopped by an iris diagram until the opposed currents just balance.

The variable currents are transformed and pass through a rectifier to a galvanometer. Since only the variable parts of the current are transmitted by the transformer, the apparatus is not affected by steady light and can be operated by day or night.

Five references.

Photographic Emulsion—Notes on Stability of Finished Plates. (B. H. Carroll, D. Hubbard and C. M. Kretchman, Bur. Stan. J. Res., Vol. 12, No. 2, Feb., 1934, pp. 223-230.) (14.60/28855 U.S.A.)

Deterioration on storing may be due to " after-ripening." Fog at the edge of the plate may be due to the migration of the soluble bromide during the drying process, which normally begins at the edges. If the drying is irregular, definite patterns may form on the plates, showing the position of eddies where the drying was slowest.

A number of organic compounds act as preservatives of photographic materials. Chief amongst these is Nitrobenziminazol. Their action is not yet perfectly understood.

Acoustics, Noise Reduction, etc.

Acoustical Device for Finding the Position of Aircraft. (Barbier, Bénard and Turenne, L'Aéron., No. 177 (Bulletin), Feb., 1934, pp. 16-21.) (15.26/28856 France.)

A sound detector follows the motion of the aircraft. By means of a series of linkages a circular spot of light travelling on a glass sheet gives the instantaneous position of the aircraft, with automatic corrections for aberration, time lag and parallax.

The instrument forms the subject of French Patent No. 687246. It appears that a more recent design, unpublished, gives temperature and wind corrections.

The Acoustical Insulation Afforded by Double Partitions Constructed from Similar Components. (J. E. R. Constable, Phil. Mag., Vol. 18, No. 118, Aug., 1934, pp. 321-343.) (15.38/28857 Great Britain.)

An increase in the air spacing between double partition walls may decrease the acoustical damping. A range of frequencies was found over which double glass windows gave less acoustical damping than a single window.

Five references.

Noise Reduction in Cabin Aeroplanes. (P. R. Bassett and S. J. Zand, Trans. A.S.M.E., Vol. 56, No. 2, Feb., 1934, pp. 49-56.) (15.38/28858 U.S.A.)

A tuning fork is set in vibration at a fixed distance from the ear and is compared with the noise to be measured. The time is measured, by stop watch, in which the intensity sinks until it is masked by the noise.

The fork has been calibrated in decibels for initial sound intensity and damping. By using a series of tuning forks of different pitches, an analysis of the frequency distribution is obtained. Over a large number of readings this simple apparatus agrees within ± 2 decibels with an elaborate noise meter measuring sound intensity directly.

In a large passenger machine insulation of the engine mounting and cabin structure, and acoustically filtered ventilation reduced the noise level from 97 decibels to 76 decibels.

Seven references.

Sound Insulating Properties of Plastic Fluid and Granulated Materials. (A. Gemant, Phys. Zeit., Vol. 35, No. 5, 15/2/34, pp. 167-171.) (15.38/28859 Germany.)

The small scale apparatus described and shown in sketch is suitable for testing circular plates of material of 20 cm. diameter and about 2 mm. thickness. A loud speaker and a microphone are fixed in the sending chamber, and microphone in the receiving chamber. The microphones set up e.m.f.s, the squares of which are proportional to the sound intensities.

Numerical results are shown graphically for rigid plates, shell oil, vaseline and water, and for various powdered substances.

Three references.

Accidents and Precautions

Damage to Aircraft by Lightning. (W. Brintzinger and H. Viehmann, Luftwissen, Vol. 1, No. 2, 15/2/34, pp. 32-35, D.V.L. Report No. 363.) (16.30/28860 Germany.)

With improved blind flying by instrument, reports from aircraft struck by lightning have become more numerous, fortunately without serious damage in most cases.

A descriptive account is given of the electrical field in which an aeroplane may be struck. The mean discharge current may be as great as 7×10^6 amperes, the duration as long as 1/1,000th second. A discharge of 50 coulombs (ampere-seconds) in 1/1,000 second will produce a rise of temperature of 500°C. in a conductor of 7 mm.^{2} copper, 16 mm.^{2} aluminium or 20 mm.^{2} iron. Control wires, bracing wires and metal coverings of ordinary dimensions are therefore safe from fusion.

The path of the current is not determined principally by conductivity, but by local reactance and capacity. Points of entry and exit and points of passage from one conductor to another across a gap of air (or other dielectric) are dangerous from the formation of arc flames with a temperature of many thousand degrees. Protection from such arcing is obtained by bonding, particularly the wireless antennæ and other metal parts.

Methods of recording the voltage are discussed and a record is reproduced from an artificial reproduction of lightning effects. A photograph of damage by arcing from a wireless lead-in to metal frame is shown.

Eleven references.

Hazards to Aircraft Due to Electrical Phenomena. (N.A.C.A. Tech. Note No. 494, March, 1934.) (16.30/28861 U.S.A.)

Risks to aircraft from atmospheric electricity are discussed. If trailing antenna and cables are reeled in there is little danger of serious damage to an aeroplane or aircraft with a metallic network properly bonded.

One reference.

Researches on Lightning Discharges Striking Aeroplanes. (R. de l'Armée de l'Air, No. 56, March, 1934, pp. 325-340.) (16.30/28862 France.)

Experiences of pilots " struck " during flight are given. High tension experiments were carried out in U.S.A. on the ground on model and full scale aircraft. Some experiments were also carried out with balloons.

The risk of damage to the structure of an aeroplane by a lightning discharge is small, with suitable bonding. If the discharge passes close to the pilot it may impose a nervous shock, not necessarily fatal in itself, but leading to temporary loss of control, with possibly fatal results. Lightning conductors should therefore be disposed so as to carry the discharge at a distance from the pilot.

Aircraft, Unorthodox

Vertical Flight. (H. H. Platt, J.R. Aer. Soc., Vol. 38, No. 282, June, 1934, pp. 507-514.) (17.05/28863 Great Britain.)

Estimates of the specific power required for vertical flight are shown graphically by illustrative curves.

A brief account is given of the cyclogiro, and figures are quoted from estimates in an N.A.C.A. Technical Note.

Two references.

Aerodynamic Analysis of the Gyroplane Rotating-Wing System. (J. B. Wheatley, N.A.C.A. Tech. Note No. 492, March, 1934.) (17.05/28864 U.S.A.)

The gyroplane is distinct from the autogyro. The rotor consists of four blades rigidly connected in opposing pairs and rotating freely under the air forces about an approximately vertical axis. Each blade pair is mounted in bearings at the hub which permit them to oscillate or feather freely about the bearing axis or feathering axis.

The author puts forward a mathematical analysis of the aerodynamics of the gyroplane. [The rotation of opposing blades as a rigid unit clearly increases the incidence of one blade and reduces the incidence of the other by equal amounts.]

Five references.

The Stipa Aeroplane. (J. Lacaine, L'Aéron., No. 176 (Suppmt.), Jan., 1934, pp. 3-8.) (17.30/28865 France.)

A comprehensive summary is given of the aerodynamical investigations of L. Stipa in connection with his aeroplane.

The tubular fuselage is designed to accommodate the wake of the airscrew without imposing any normal pressures, and has first a contraction, then a divergence, of the hollow section of rotation in accordance with airscrew calculations. Observed lift drag and distribution of pressure are plotted for a complete model.

Photographs show the aeroplane in flight, and a table of characteristics and performance is given. A set of six photographs shows the streamlines round and through a model, with and without engine, at different angles of incidence. Two- and three-engine models with double and triple tubular fuselages are shown.

A 120 h.p. experimental machine has been built, and the performance is comparable with machines of normal design.

Man-Power Flight. (E. Everling, Luftwissen, Vol. 1, No. 2, 15/2/34, pp. 35-38.) (17.40/28866 Germany.)

The available power of human muscles is set as high as 2.5 h.p., but even this is insufficient to maintain in the air the weight of pilot and machine. A flapping machine is described and shown in a flapping glide. (See Abstract 28867.)

Seven references.

Possibility of Flight by Muscular Power. (H. Haessler, Flugsport, Vol. 26, No. 1, 10/1/34, pp. 2-6.) (17.40/28867 Germany.)

It is estimated that a trained athlete weighing 60 kg. is capable of exerting 1.2 h.p. for one minute pedalling an airscrew. It is proposed to catapult into the air a glider with the pilot in a recumbent position, in the expectation that he could maintain flight for about a minute.

End Plates on Glider Wings. (W. Fiedler, Flugsport, Vol. 6, No. 2, 24/1/34, pp. 27-29.) (17.40/28868 Germany.)

The wings of the Fledermaus F.1 had a span of 16.6 m., area 15.15 sq. m., mean chord 0.93 m. Vertical hinged flaps were fitted at the wing tips and set at 5° yaw angle (apparently outwards). Increase in yaw angle of the flap produces increase in drag and sets up a yawing moment. The air reaction acts outwards from the centre of curvature of the aeroplane's path, against side-slipping. The induced resistance of the wing as a whole is decreased.

The flaps can be used together as air brakes to reduce the gliding angle in a forced landing. No comparative test figures are given.

Aerodynamics and Hydrodynamics

Experiments on Settling of Airborne Dust. (E. Kilb, F.G.I., Vol. 5, No. 1, Jan./Feb., 1934, pp. 6-13, and No. 2, March/April, 1934, pp. 89-94.) (22.0/28869 Germany.)

Particles were separated by sifting through sieves of 10, 20, 24, 40, 50, 70 and 80 meshes per cm., giving corresponding fractions. Various fractions were allowed to fall in a chamber with still air free from convection currents.

A photograph shows two " targets " with approximately circular symmetry, and sets of curves show frequency distributions not far from normal error curves, for different heights of fall and mean particle size. Plotting dispersion against height of fall on a logarithmic scale gives slightly curved loci. Straight lines would correspond to an approximate fit by the exponential function with appropriate parameters.

The distribution in a turbulent jet of air is also examined experimentally. A photograph shows an elongated approximately elliptical " target." Frequency distributions are analysed numerically and the results are tabulated.

In Part II non-dimensional parameters are discussed, with a view to applying the results to full scale conditions.

Nineteen references.

The Coefficient of Resistance as a Function of Reynolds Number for Solids of Various Shapes. (H. Wadell, J. Frank. Inst., Vol. 217, No. 4, April, 1934, pp. 459-490.) (22.10/28870 U.S.A.)

The influence of departure from circular sections on resistance is shown graphically. The results have applications in industrial processes depending on sedimentation.

Sixty-five references.

The Vertical Oscillations of Floating Bodies. (A. Dimpker, W.R.H., Vol. 15, No. 2, 15/1/34, pp. 15-19.) (22.10/28871 Germany.)

Four cylinders of different cross-sectional forms, and of length a few mm. less than the tank width, were constrained to oscillate in a vertical plane under spring control. The mounting of the apparatus is shown in a diagrammatical sketch. The four sections were a circle, a rectangle with a semi-circle on lower face, an equilateral triangle with vertex downwards, and a flattened rectangle with rounded corners. Free and forced oscillations and wave formations were observed.

Approximate methods of calculation are developed and discrepancies were expressed in terms of apparent mass. The period, coefficient of damping (observed), and apparent mass (calculated) are shown graphically as functions of the maximum depth of immersion; for small frequencies and amplitudes the waves formed were parallel to the cylinder, but for larger amplitude, " against all expectation," transverse waves were formed of which examples are shown in three photographs.

Motion of an Elliptic Cylinder Through a Viscous Fluid. (G. J. Richards, Phil. Trans. Roy. Soc., Vol. 233, No. A.726, 18/7/34, pp. 279-301.) (22.10/28872 Great Britain.)

A list of mathematical and experimental papers is given.

The two-dimensional equations of viscous fluid motion are put in undimensional form and transformed, in a manner due to Bairstow. A formal integration introduces an arbitrary harmonic function (as a consequence of the elimination of the pressure in the usual way).

A method is described of determining the actual streamlines by stroboscopic photography of small carrier particles under high illuminations. The harmonic function referred to is determined from values at two contours—experimental values along the elliptic boundary and known values at infinity.

Methods of integration on the assumption of steady motion are described, and the calculated values are compared with experiment. Agreement is found only in the upstream field of velocity where the field is steady. Downstream the formation of eddies obviously renders the assumption invalid.

Six photographs are reproduced and show velocity fields, particularly the vortex street behind the cylinder.

The Flow Process of Glass in Melting Furnaces. (A. Schild, Z.V.D.I., Vol. 78, No. 13, 31/3/34, pp. 411-414.) (22.10/28873 Germany.)

The flow of glass in the furnace takes place under very small Reynolds number and can be studied by the use of hydraulic models.

Five references.

New Quantitative Experiments on the Generation of Turbulence. (L. Schiller, Z.A.M.M., Vol. 14, No. 1, Feb., 1934, pp. 36-42.) (22.15/28874 Germany.)

Experiments on tubes with various forms of entry led to the view that general turbulence is set up when the circulation in the vortices carried down the tube reach a certain limiting value. The wave length of the disturbance is an important factor.

The results are compared with observations of flow over a flat plate.

Eight references.

Turbulence and Skin Friction. (T. v. Karman, J. Aer. Sci., Vol. 1, No. 1, Jan., 1934, pp. 1-20.) (22.15/28875 U.S.A.)

Consideration is given to the effect of roughness. A " roughness scale " for materials used in practice is required and further study should be given to the transition ranges in which both the Reynolds number and the roughness parameter influence the friction.

Twenty-four references (since 1930).

Skin Friction Correction. (L. Bairstow, Airc. Eng., Vol. 6, No. 67, Sept., 1934, pp. 245-246.) (22.15/28876 Great Britain.)

A brief resumé covers much the same ground as the previous Abstract (see Abstract 28875).

Reference is made to the remarkable results of Nikuradse on artificially roughened pipes, in which the introduction of a roughness parameter reduces a number of experimental curves to a single unicursal curve in appropriate non-dimensional co-ordinates.

Thirty-three references.

Resistance of Rough Plates. (L. Prandtl and H. Schlichting, W.R.H., Vol. 15, No. 1, 1/1/34, pp. 1-4.) (22.15/28877 Germany.)

The experimental results obtained by Nikuradse on flow in rough pipes (Forschungsheft No. 361, see Abstract 27678) are quoted in terms of the parameter r/k, where r is the radius of a pipe, k the mean amplitude of the roughening of the surface. For a flat plate Reynolds number is expressed in terms of k and of a velocity parameter defined as the square root of the ratio of the tangential pressure on the walls to the density.

Four distinct ranges are covered by numerical values of the Reynolds number thus defined :—

$$R = \infty,\ 71,\ 14,\ 7.1,\ \text{zero.}$$

They are designated as completely rough, second transition range, first transition range and hydraulically smooth.

Extensive transformations of semi-empirical formulæ are carried out and the expressions obtained are tabulated numerically.

Graphical charts are given which enable numerical values of local and total resistance to be read off.

Four references.

Distribution of Hydraulic Energy in a Free Stream Dropping Vertically. (C. Rappert, Z.V.D.I., Vol. 78, No. 1, 6/1/34, p. 31.) (22.2/28878 Germany.)

Using the impulse theorem a simple relation is obtained between the total pressure, potential energy, mean speed and thickness of the jet. The formula is verified by experiment.

Two references.

Relation between the Temperature Coefficient of Viscosity and the Association of High Molecular Liquids. (B. Yamaguchi, Aer. Res. Institute, Tokyo, Report No. 102 (Vol. 8, No. 6), Feb., 1934.) (22.2/28879 Japan.)

The viscosity is expressed as a product of a constant coefficient and two functions depending on the molecular associations and the molecular structure.

Increase of concentration of a polar solute in a non-polar solvent increases the molecular associations, not necessarily affecting the molecular structure. With increased concentration an increase in viscosity due to molecular association is superposed on the linear increase due to increased proportion of polar molecules. Increase of temperature decreases the molecular association likewise without necessarily affecting the molecular structure.

These simple considerations lead to useful correlations over a wide range of experimental facts. Extensive data are given in tables and curves and exhibit viscosity relations of fifteen lubricating oils and of ten other organic substances, including para rubber.

In particular a physical explanation is suggested for the well known fact that oleic acid and the fatty oils have a low temperature coefficient of viscosity. The same holds true for voltol oils and lubricating oils made by the polymerisation of olefines. The low temperature coefficient of viscosity of rubber solution is also of interest.

Investigation of Errors in Flow Through Standard Orifice Due to Inaccurate Mounting. (Fr. Kretzschmer and G. Walzholz, F.G.I., Vol. 5, No. 1, Jan./Feb., 1934, pp. 25-35.) (22.2/28880 Germany.)

Coefficients of flow, the flow being taken as proportional to the square root of the pressure drop across the diaphragm, are examined for errors due to faulty mounting. The values of the coefficients derived from direct measurement are compared with the values given by German standard rules and the errors are analysed as far as possible and tabulated for systematic changes in the variables, diameter of pipe, diameter of perforation in diaphragm, thickness of diaphragm, roughness of pipe walls, etc. In general the error lies within the given tolerations, but in certain cases exceeds them.

Fourteen references.

Coefficient of Discharge of Standard Nozzles and Orifices under Inflow and Outflow Conditions. (E. Stach, Z.V.D.I., Vol. 78, No. 6, 10/2/34, pp. 187-189.) (22.2/28881 Germany.)

The air meter is usually inserted at some distance from the end of the pipe line, but in certain conditions it is necessary to place it at the end. The author has compared the coefficients of discharge obtained under both conditions.

With inflow the discharge coefficient was found to be constant, both for nozzle and orifice, provided Re exceeded 0.55×10^5. Its value exceeds slightly the standard value. Under outflow conditions the variations with Re are greater. The maximum difference from the standard mounting may amount to ± 1.5 per cent.

Two references.

Friction of Water Circulating in Water-Tube Boilers. (E. Schmidt, P. Behringer and W. Schurig, Forschungsheft, No. 365, March/April, 1934.) (22.2/28882 Germany.)

Experiments were carried out at pressures up to 40 atmospheres on a boiler consisting of four tubes arranged in the form of a rectangle, the two longer limbs being vertical. One of these was heated electrically and the circulation was measured by an orifice meter placed near the lower end of the other vertical limb.

The heat transfer coefficient was found to be practically independent of the rate of circulation, showing that the scrubbing action is entirely due to steam bubbles. The friction of the mixture of steam bubbles and water was measured directly by the apparent loss of weight of a thin brass liner supported inside the vertical boiler tube.

Thirty-three references.

Oscillations of a Plate at the Surface of a Fluid. (A. Dimpker, Ann. d. Phys., Vol. 19, No. 3, Feb., 1934, pp. 225-251.) (22.35/28883 Germany.)

The problem is first restricted to a periodically " loaded line " and is then extended to a loaded plate of finite breadth. The initial and boundary conditions are defined in an arbitrary manner, so as to facilitate solution of the two-dimensional problem, which is obtained by application of Fourier integrals, Bessel functions and Fresnel functions. The results obtained by Cauchy and Poissons are recorded.

The experimental installation in the latter part of the paper is mounted as described in the author's paper abstracted above (see Abstract 28871).

The observed values are plotted for comparison with computed values and show satisfactory agreement of the main wave, with superposed harmonics with amplitude of the order of 11 per cent. of the fundamental. A photograph shows waves produced experimentally.

Four references.

Surface Tension Measurement by Ripples. (H. E. Becket and H. Sheard, J. Sci. Inst., Vol. 11, No. 7, July, 1934, pp. 214-216.) (28884 Great Britain.)

A description is given of an optical apparatus for viewing standing ripples on the surface of a fluid of known density. From the observed frequency and wave length the surface tension is calculated by Kelvin's formula. The results have an error of the order of $1\frac{1}{2}$ per cent.

Wind Channel Tests on Air Resistance of Railway Trains. (G. Vogelpohl, Z.V.D.I., Vol. 78, No. 5, 3/2/34, pp. 159-167.) (22.4/28885 Germany.)

A model train of German corridor express coaches of orthodox modern designs was suspended close to a model of the permanent way attached to a plate. The plate was fitted with a stationary streamline nose and tail pieces between which the model could oscillate. The resistance of a single coach was measured in different positions in the train. The shape of the coach ends had a predominant effect on the resistance.

Experiments in a water channel with flat sectional models gave two dimensional configurations of flow for different shapes. The amount of ventilating air entering the coaches, especially through open windows, was an important factor.

Goods trains with open empty trucks showed greater resistance than with covered trucks.

By designing the spacing and ventilation in accordance with these experiments, without departing from orthodox design, the air resistance could be reduced by about 25 per cent.

Thirty-two references.

Wind Pressure on Chimneys. (R. Fleming, Engineering, Vol. 138, No. 3577, 3/8/34, pp. 123-5.) (22.4/28886 Great Britain.)

The assumed wind pressure coefficients for various chimneys are given. Reference is made to a list of tall chimneys, including the 752ft. chimney built in 1917 at Tacoma, Washington.

Experimental aerodynamical results are quoted in relation to Reynolds number, and working formulæ are given.

Eighteen references.

Influence of Neighbouring Structure on Wind Pressure on Tall Buildings. (C. L. Harris, Bur. Stan. J. Res., Vol. 12, No. 1, Jan., 1934, pp. 103-118.) (22.4/28887 U.S.A.)

A photograph shows a model of the Empire State Buildings and of neighbouring buildings, the former pierced by pressure orifices distributed at three different levels.

Pressure distribution and resultant forces and bending and torsional moments were measured in the 10ft. wind channel and are recorded graphically and in tables, the distribution being quite different from the usual assumptions.

Shielding is greatest when the shield is up stream, and the shielded area is not so high as the shield. The coefficient of resistance was found to be 0.0038 in ft. lb. (gravitational) units.

Some recommendations are given for designers.

Eight references.

Drag of Streamline Bodies. (M. H. Lyon, Airc. Eng., Vol. 6, No. 67, Sept., 1934, pp. 233-239.) (22.4/28888 Great Britain.)

A concise summary is given of results accumulated by years of patient research. Rational results for laminar flow and semi-empirical results for turbulent flow are combined to yield the total drag of the tangential force.

The effects of previous turbulence remain obscure, and due caution is observed in the interpretation and application of model and full scale experiment to design.

Twenty references.

Measurement of Velocity Variations in Turbulent Flow. (L. F. G. Simmons and C. Salter, Proc. Roy. Soc., Vol. 145, No. A.854, 2/6/34, pp. 212-234.) (22.45/28889 Great Britain.)

The peculiarities of hot wire instruments are discussed, and Kuethe's formula for time lag is quoted. The sensitivity of the circuit is improved by amplification and separation of high frequency effects. A diagram of connections shows the general arrangement, and formulæ are given for the relevant characteristics.

An oscillograph is controlled by the current, and the beam traverses a band on a sensitive plate repeatedly. The density of the band is measured in accordance with previous calibration and determines the duration distribution of the variable component of velocity. Methods of reducing and transforming the results are fully described.

Application was made to the analysis of free stream turbulence and to the eddy formation behind a grid in a 1ft. channel at a speed of 5.3ft. per sec. at

various distances downstream. Close behind the grid the wake of each strip is clearly marked. Some 10ft. downstream the distribution of the eddy components appears to approach the normal error curve.

Two references.

Researches Carried Out in the Physical Laboratory of the French Air Ministry. (L'Aéron., No. 178 (Bulletin), March, 1934, p. 28.) (22.45/28890 France.)

Heating in the boundary layer at high air speeds is measured by thermocouples at centre and periphery in the surface of a rotating disc. A high speed sliding contact is required.

A temperature rise of 4°C. was found to correspond to a peripheral speed of 100 m. per sec.

Turbulent Diffusion of a Jet. (E. Forthmann, Ing. Arch., Vol. 5, No. 1, February, 1934, pp. 42-54.) (22.5/28891 Germany.)

The wind channel and measuring apparatus are shown in photographs and sketches. Pitot-mean velocity distributions are plotted graphically and reduced to a unicursal curve with small scattering by introduction of non-dimensional parameters (see Abstract 27674).

An interesting result is the distribution of apparent mean shear across a jet with a free air boundary on one side. Pitot-mean axial velocity distribution is also plotted for a sudden widening in the channel. Semi-empirical expressions are developed and transformed in the manner of Prandtl, v. Karman, and others.

Nine references.

Turbulence in the Flow of Air Through a Pipe. (H. C. H. Townend, Proc. Roy. Soc., Vol. 145, No. A.854, 2/6/34, pp. 180-211.) (22.5/28892 Great Britain.)

A series of sparks between very fine electrodes heats a succession of small volume elements which are observed by the refraction of a beam of light.

By suitable optical arrangements the beam is rendered convergent, preferably by concave mirrors, and the image reduced to the size of a cinema film.

A photograph shows the installation, and examples of records are reproduced. The records were used to analyse the turbulence in air flow, and the distribution of the observed velocity components is compared graphically with the normal error curve. Comparison with ultramicroscope observation showed satisfactory general agreement, with anomalies at low values of one component near the axis.

The turbulent kinetic energy is expressed as a fraction of the total kinetic energy for small tubes of mean flow and appears to be less than 3 per cent. of the total.

Comment is made on an approximate theory suggested by v. Karman, from which it appears that considerable modifications will be required to bring it into line with experiment.

Eight references.

Materials, Elasticity and Plasticity

Destruction of Materials by Cavitation. (H. Schröter, Z.V.D.I., Vol. 78, No. 11, 17/3/34, pp. 349-351.) (23.0/28893 Germany.)

Samples of various substances were exposed to a stream of water with a velocity of 40 to 60 m. per sec., under conditions favouring cavitation. Loss of weight was measured and surface pitting examined. Sensible changes were observed in heat-treated alloy steels after 48 hours' exposure, and in lead after one minute. Rubber was destroyed in about three minutes.

The effects are restricted to the region of collapse of vapour-filled bubbles in contact with the test piece. The impact forces are not sufficiently great to account for the direct destruction of the surface and electro-chemical reactions must take place.

Two references.

Extensions of Prandtl's Membrane Analogy. (W. Bauersfeld, Ing. Arch., Vol. 5, No. 1, February, 1934, pp. 69-82.) (23.0/28894 Germany.)

The well-known analogies between the slope of an elastic membrane torsion field of stress and streamlines are discussed fully, in particular the velocity field round an aerofoil with circulation imposed on irrotational flow.

The contours are rendered visible by narrow sheets of intense light. Two velocity fields with tangential motion at the trailing tip are reproduced. Applications to the velocity field round turbine blades set radially are also discussed, and the mounting of the experimental apparatus is shown in sketches.

Eleven references.

Allowable Working Stresses Under Impact. (N. N. Davidenkoff, Trans. A.S.M.E., Vol. 56, No. 3, March, 1934, pp. 97-107.) (23.10/28895 U.S.A.)

This paper by the Head of the Mechanical Deparment of the Leningrad Technical Institute gives a summary of European research.

The yield point and tensile strength of a material under impact are always greater than those given by low speed tests. The working range should, however, remain within static limits. Impact tests on notched specimens cannot be used to determine allowable stresses.

The paper is followed by a useful discussion.

Fifty-five references.

Sensitivity of Materials to Notch Test. (W. Buchmann, F.G.I., Vol. 5, No. 1, Jan./Feb., 1934, pp. 36-48.) (23.10/28896 Germany.)

Ultimate strengths of ten steels subjected to tensile and bending tests under static and alternating loads are given in numerical tables. Stress optical methods are illustrated by a glass model.

A wide range of applications is considered, and numerical results are given graphically. Applications to design are discussed.

Twenty-six references.

The Testing of Materials. (F. Korber, Z.V.D.I., Vol. 78, No. 6, 10/3/34, pp. 195-199.) (23.10/28897 Germany.)

Tests to destruction of composite engineering products are expensive and of doubtful value, since it is difficult to reproduce working conditions. Factors of importance are—rate of application and distribution of load, vibration and corrosion. Information from test pieces in the laboratory must be used with discretion.

Stress optical methods give useful indications of stress distribution in the final product under working conditions. Recently X-ray investigation has also produced useful results.

Eleven references.

Present Stage of Development of Non-Destructive Methods of Material Testing. (X-ray and gamma radiation.) (R. Berthold, Z.V.D.I., Vol. 78, No. 6, 10/2/34, pp. 173-181.) (23.10/28898 Germany.)

X-ray investigation of the internal condition of engineering products has developed rapidly. It is now current practice for examination of light alloy

castings, high pressure steel bottles, reinforced concrete, steel cables, welds, adhesion of bearing metals, etc.

More recently radium preparations have been applied to the examination of inaccessible parts. Various forms of apparatus are described, and consideration is given to the reduction of secondary radiation—which produces disturbing effects.

Thirty-eight references and twenty-one photographs.

Distribution of Stress in Rotating Plastic Disc. (H. Schlichting, Ing. Arch., Vol. 5, No. 1, February, 1934, pp. 7-24.) (23.10/28899 Germany.)

Simple non-linear forms of stress-strain relations are assumed and the elastic equations are modified accordingly. The modified differential equation for a rotating disc is formed and solved by approximate methods.

The lengthy expressions obtained involve a large number of approximate numerical coefficients. The results are shown graphically in thirteen diagrams. The angular velocity of rupture may be computed from the final equations.

Twenty-five references.

Determination of Peak Stresses in Shafts Under Torsion, Using an Electrical Model. (A. Thum and W. Bantz, Z.V.D.I., Vol. 78, No. 1, 6/1/34, pp. 17-19.) (23.10/28900 Germany.)

Even in two-dimensional problems, the solution of the differential equation of elastic deformation is prohibitive unless the boundary conditions are of a few special types. The author describes a simple apparatus which gives analogous two-dimensional fields of electric potentials. Alternating current is led into a shallow trough filled with water, the boundary of the trough being similar to the section.

Peak stresses are indicated by crowding of isopotential lines.

Fourteen references.

Faults in a Material Yielding to Shear Stress while Retaining its Volume Elasticity. (G. I. Taylor, Proc. Roy. Soc., Vol. 145, No. A.854, 2/6/34, pp. 1-18.) (23.10/28901 Great Britain.)

Plastic substances are classified according as the maximum stress increases or decreases after local yielding first appears. In the former case the stress on the volume element which has yielded locally increases less rapidly than on the other elements, and the plastic deformation tends to distribute the stresses equally.

In the second case the element which has yielded loses its shear strength completely and throws increased stresses on the remaining elements. A mathematical theory of strain and failure has been constructed on the second hypothesis and is applied in explanation of the rules given by v. Mises and Mohr.

The theory also predicts the propagation of cracks along their initial direction, both when parallel to and at 45° with the principal stresses.

Six references.

Yield Points of Mild Steel Beams Under Uniform Bending. (F. Nakanishi, M. Ito and K. Kitamura, Aer. Res. Institute, Tokyo, Report No. 104 (Vol. 8, No. 8), March, 1934.) (23.30/28902 Japan.)

In tensile mild steel beams of T section, usually the material on one side of the axis yields before the material on the other side. This produces two distinct yield points which are shown on four experimental stress-strain diagrams. These points are calculable on simple assumptions and a satisfactory fit is obtained with experiment.

Nomograms for Dimensioning of Compression Rods of Tubular Section. (W. Lohmann, Z.V.D.I., Vol. 78, No. 12, 24/3/34, pp. 386-387.) (23.30/28903 Germany.)

The nomograms apply to three standard qualities of steel tubing for ranges of 30-200 mm. mean tube diameter, 1 mm. to 25 mm. gauge thickness, 0.4 to 10 tons buckling loads, and 0.5 to 15 metres buckling length.

For each specified quality of steel the corresponding values of diameter, length, gauge and buckling load are read off.

Three references.

Stability of Elastic System Under External Forces Affected by the Deformation. (Carlo Minelli, L'Aerotecnica, Vol. 14, No. 1, Jan., 1934, pp. 3-26.) (23.40/28904 Italy.)

The energy criteria of Bryan and Timoshenko is restricted to arbitrary external forces. The present paper extends the results to the case where the external forces are functionally connected with the strains.

Elementary examples are constructed to illustrate the principles. The method is applied to a wing in torsion, the angle of torsion about the axis of torsion being taken as an independent variable.

The equation of energy is formed in the usual way, and approximate solutions are obtained by expansion of the torsion in terms of distance along the wing span. Comparison with more rigorous formulæ shows that sufficient accuracy for technical purposes is attained by comparatively elementary mathematical analysis.

Seven references.

Developments in Aircraft Construction. (H. J. Pollard, J.R. Aer. Soc., Vol. 38, No. 283, July, 1934, pp. 652-686.) (23.41/28905 Great Britain.)

The strength of thin sheets with flanges or stiffeners is discussed at length, and examples of the type of failure at buckling load are shown in photographs. The elements of an approximate theory are stated. Welding and riveting are considered briefly from the constructor's point of view. Corrosion is briefly referred to.

A discussion brought out the difficulties of establishing a more complete theory and elicited the views and some experiences of other designers.

Twenty-three references.

Structural Analysis by Electrical Analogy. (V. Bush, J. Frank. Inst., Vol. 217, No. 3, March, 1934, pp. 289-330.) (23.45/28906 U.S.A.)

The linear differential equations with constant coefficient of internal strain energy lead to systems of equations of the same form as for corresponding electrical networks, and the solution depends on identical systems of linear equations.

By setting up electrical circuits and measuring the currents, numerical values are obtained experimentally (see Abstract 28907).

Five references.

Miscellaneous

Mallock Electrical Calculating Machine. (Engineering, Vol. 137, No. 3571, 22/6/34, pp. 698-700.) (28907 Great Britain.)

Let n shorted electrical circuits be interlinked with $(n+1)$ magnetic circuits and let a_{pq} be the number of turns of electrical circuit p interlinked with magnetic

circuit q, then an induced flow in magnetic circuit q produces e.m.f.'s in the electrical circuits, satisfying the linear equation:—

$$a_{1q}\rho_1 + a_{2q}\rho_2 \ldots + a_{n+1,\ q}\rho_{n+1} = 0.$$

The e.m.f.'s $e_1 \ldots \rho_{n+1}$ are read off a volt meter.

Applying this to each circuit in turn we obtain the numerical solution of the system of simultaneous linear algebra

$$\begin{matrix} a_{11}\rho_1 + \ \ldots\ a_{1,\ n+1}\,\rho_{n+1} = 0 \\ a_{n1}\rho_1 \qquad\quad a_{n,\ n+1}\,\rho_{n+1} = 0. \end{matrix}$$

The coefficients can be set from $-1{,}000$ to $+1{,}000$.

Mechanical and electrical details are described and illustrated by diagrams and photographs. The voltage errors due to resistance drop are of the order of $\frac{1}{4}$ per cent.

Refinements of method, compensations and second approximations reduce the final errors, and powerful checks are easily made. Other applications are described and the suggestion is made that a central office be set up where solutions are carried out for a clientele which is potentially at least already in existence.

Applied Mechanics Congress—Summaries of Papers of 4th International Meeting. (Airc. Eng., Vol. 6, No. 66, Aug., 1934, pp. 215-219.) (28908 Great Britain.)

Useful summaries of 25 papers are given.

REVIEWS

Aerodynamic Theory

Edited by W. F. Durand. Published by Julius Springer, Berlin. Price R.M. 20.

This is the second volume of a work published under a grant given by the Guggenheim Fund for the Promotion of Aeronautics, the principal object being to provide for the aeronautical designer a reasonably adequate presentation of fundamental theory.

The present volume is by Prof. von Kàrmàn and Prof. J. M. Burgess, and starts with a chapter on the flow round an aerofoil, followed by chapters on the Theory of Aeroplane Wings of Infinite Span, the Mathematical Foundation of the Theory of Wings with Finite Span, Aerofoils and Aerofoil Systems of Finite Span, Problems of Non-Uniform and of Curvilinear Motion, the Development of the Vortex System Downstream of the Aerofoil, and the Theory of the Wake. These are followed by an excellent bibliography and an index.

This book is an important addition to aircraft literature. It contains a very good presentation of aerofoil theory in its present state of development, written by authors who know the subject intimately, and, for the first time, this information is collected into one book, where it can easily be referred to by the designer. Naturally, a reasonable equipment of mathematics is necessary if the book is to be properly understood, and there is no doubt that those who depreciate the value of higher mathematical training place themselves under a serious handicap by depriving themselves of the information given here.

The book is extremely valuable, it is well written and well printed and can be thoroughly recommended to all those designers and others who wish to understand the theoretical side of aviation.

Making It Happen

By George Taylor. Published by Robertson and Mullens, Ltd., Melbourne.

This book contains a biography of Sir Macpherson Robertson, who recently became prominent in this country as the donor of the prizes for the recent International Air Races between London and Melbourne.

It describes in some detail his early struggles under most difficult financial conditions, his enterprise in starting a sweet business in Australia, and his rise to fame as a wealthy manufacturer, the founder of a firm making all types of sweetmeats from acid drops to chocolate. The book is almost entirely concerned with business activities, and where technical details are given it is sometimes difficult for those who do not understand the track to follow the description. There are hardly any personal details and, after reading the book, one does not even know definitely whether Sir Macpherson is married, though from the absence of any reference to the subject it may perhaps be inferred that he is not.

He seems to be a typical example of the best type of self-made man, to be a born leader and to possess abundant foresight and business acumen. His generosity is naturally better known in Australia than here, and it may not be generally known that the cost of the prizes for the co-called MacRobertson race were part of a gift of £100,000 that he presented to the State of Victoria for the celebration of the first 100 years of its history. When £42,000 of this amount

was claimed by the Commonwealth Government as taxation, he paid the tax himself, in addition to the original gift.

The MacRobertson air race to Australia was undoubtedly a great conception, and its effect on imperial communications and the design of commercial aircraft cannot yet be adequately judged. But there is already no question whatever that Sir Macpherson's gift has stimulated the design of long-distance aircraft in a way which nothing else has so far succeeded in doing, and that the benefits that the Empire may expect from this stimulus will greatly exceed the cost.

Aviation Memories

By Owen Cathcart-Jones. Published by Hutchinson and Co., Ltd. Price 12/6.

It has not infrequently happened that the accomplishment of a notable flight by an air pilot has been followed by a book describing his upbringing and career. The anxiety of the publishers to get the book out before the public, notoriously lacking in memory, has forgotten the feat and the man who did it, is responsible for works which have obviously been hastily written and which suffer in consequence. It is, however, only fair to say that this book suffers less from this defect than some of the others.

It is mainly an interesting account of the experiences of a naval officer who transferred to the Fleet Air Arm and of the various things which happened to him. We are told how he learnt to fly, what it feels like to land on the deck of an aircraft carrier, and something about the life on board and the relations between the Air Force and the Navy. The author was engaged in the air operations in China in 1926-7 and has much that is interesting to say about his personal experiences. In 1930 he left the Service and became a civil pilot, and after doing some ordinary civil flying, flew to Capetown with Glen Kidston in 6 days 11 hours in an American aeroplane. The book terminates with a short description of the author's Australia and back flight which only takes up some twelve pages, and which tells us nothing that has not previously been published. The book is to be commended for its descriptions of life in aircraft carriers and will be found interesting to those who are thinking of joining the Fleet Air Arm. There is little of technical interest.

Airplane Design

By Prof. K. D. Wood. Published by the College of Engineering, Cornell University.

This work is intended for use as a textbook in aeroplane design for the use of undergraduates at Cornell University, where Prof. K. D. Wood is Assistant Professor of Engineering. The object of the book is instruction in aeroplane design in its preliminary stages.

The procedure given for the process of design is necessarily of a simple character and the method adopted is to take a supposititious aeroplane and to carry out the numerical calculations connected with it, obtaining the data from curves or published reports, with the result that the student would obtain a general idea of the sort of calculations which would be required for the calculation of an aeroplane of the normal type. In certain cases, where adequate investigation might mean delving into mathematics which would be beyond the normal undergraduate, the author has had to bring in dogmatic statements of his own, a procedure which is probably unavoidable.

It follows, therefore, that to the experienced designer this part of the book does not present much interest, but, in addition to the articles on design methods, there is a very large amount of data on costs and structure weights, much of which seems to be new. The costs data goes into considerable detail. Graphs are given of the costs of most of the aeroplane raw materials and there are even

tables giving the time taken for servicing operations on the various parts when these require attention on service. One gathers, for instance, that it should be possible to remove and replace the tail surface on a 20,000lb. aeroplane in some four hours, and inspect the work in two hours. In fact, the general information is dealt with very extensively and many of the details given are of much interest, though, owing to the difference in English and American practice, they may not be capable of direct application to design in this country. There are numerous illustrations of detailed parts showing methods of constructing spars, ribs, control gears, and also of standard types of aeroplanes, and many pages are devoted to the sort of data that is to be found in every engineering handbook.

If an undergraduate had thoroughly mastered this work he would obtain a general but superficial knowledge of aircraft design. If his capabilities were above the average he might be able to work out accurately the estimates and drawings for an aeroplane of normal type, but if he wished to produce a design in which modifications from the normal had been made he would find himself in difficulties. But this is inevitable, for it is impossible for anyone to become an expert designer from the reading of a book.

There seems to be a considerable divergence between the methods used in teaching aeronautics in Cornell University and those used in English Universities. In this country, the University course consists mainly of theoretical instruction and much of the information in this book would not normally become known to the English undergraduate until he left his University for a commercial job. It would be interesting to know whether less stress is laid on theory at Cornell, or, if not, how it is possible to find time for both theory and such practice as is exemplified in this book.

Physical and Dynamical Meteorology

By Prof. D. Blunt. Published by the Cambridge University Press. Price 25/-.

This book consists of an account of theoretical meteorology as far as it is understood at the moment, and it is intended to act as a textbook for post-graduate students. There are also descriptions of observed phenomena, especially in those cases where theoretical considerations have failed to find any explanation of the facts.

It is probable that it is more difficult to make headway in meteorology than in any other branch of scientific investigation owing to the extreme complication of the subject. The observed phenomena depends on the laws of thermodynamics combined with those of aerodynamics and there are many other important ingredients, such as radiation and absorption phenomena, which bring in the laws of physics in general. The result is a hotch-potch of complicated happenings, occurring on a vast scale which the resources of science so far have been unable to unravel. Even the explanation of the origin, maintenance, travel and death of cyclones and anticyclones is at present unknown.

The book is an important and valuable addition to the literature of the subject and it should be of great value to those engaged in the profession of meteorology. To others, there is much to be learnt from the book on general scientific methods of investigation as applied to the solutions of problems of surpassing difficulty. It is clear that considerable progress has been made towards understanding atmospheric phenomena, and that, although present knowledge is not sufficient for our needs, there is considerable hope for the future.

The 581st Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

A meeting of the Royal Aeronautical Society was held in the lecture theatre of the Royal Society of Arts, 18, John Street, Adelphi, London, W.C.2, on Thursday, November 8th, 1934, for the reading and discussion of a paper by M. Louis Breguet on "Speeds of Commercial Aeroplanes." Lieut.-Col. J. T. C. Moore-Brabazon, President of the Society, in the chair.

The PRESIDENT: In introducing M. Breguet, he said the Society was extremely fortunate not only in having a paper presented by one so distinguished throughout the world, but also by reason of the fact that M. Breguet should have presented it at such a singularly opportune time; he did not think the Society could have asked anyone more distinguished to deal with speed in civil aviation—a subject which had occupied the minds of the people of this country so largely recently. M. Breguet had carried out his first experiments in aviation in 1905. In 1906 he had constructed, erroneously, a gyroplane; in 1907 he had made his first attempt to fly with a 40 h.p. motor and had remained in the air for one minute. That might not sound a lot, in view of later developments, but in those early days it was a very remarkable feat. In 1910 he had made his first real cross-country flight, between Douai and Arras—quite a noteworthy thing in those days—and was a prominent competitor at the great meeting at Rheims, when he had astonished the world by taking up no less than 11 passengers in this aeroplane. Until that time it was about as much as one could do, as a rule, to carry one's own boots; so that to carry 11 passengers was a very remarkable feat. From that time he had grown from strength to strength, and had become one of the most prominent French manufacturers, not only of war machines, but also of civil machines. Having regard to his experience and his comprehensive ability to review the whole situation, his words on civil aviation and the speed of civil machines would be of great interest.

M. BREGUET: He would like first of all to express his appreciation of the great honour of addressing the members of this learned Society devoted to aeronautics, which was founded in 1866—six years before the foundation of the Société Francaise de Navigation Aérienne, for the same purpose, and of which he was President. He returned thanks to the President of the Society for the kind things he had said by way of introduction; and, inasmuch as the paper was written in a language other than his own, he asked Colonel Mervyn O'Gorman, whom he was glad to greet as an old friend, to read the paper on his behalf.

Colonel O'Gorman then read the paper.

SPEEDS OF COMMERCIAL AEROPLANES*

BY

LOUIS BREGUET

It is a great honour for me to address the members of the oldest learned society devoted to aeronautics, the Royal Aeronautical Society, which was founded in 1866—six years before the Société Française de Navigation Aérienne of France was founded for the same purpose.

The choice of a subject nowadays is a difficult matter; great progress has been made in aeronautical science—numerous research workers all over the world are endeavouring to solve the outstanding problems—and the reason I decided to take for my lecture the subject of the maximum speeds of commercial aeroplanes was that it appears to me to be a matter of the utmost importance for the future of commercial aeronautics and for linking up the different peoples of the globe.

This problem of speed is of interest in all methods of transport, and it is one that receives the constant attention of technicians, air transport companies, and passengers.

Moreover, nowadays it is almost banal to dwell on the desirability of speed in civil aviation when the air is free from obstacles, and it would be abusing an audience so well informed as you are if I were to decide to justify such a statement.

My intentions are therefore quite different. While examining the construction and the utilisation of commercial aeroplanes from the technical point of view, I intend particularly to refer briefly to the principal possibilities of increasing the speed of aeroplanes, to estimate the importance, and to proportion the expenses which certain people have hitherto believed to be too high.

First of all it may be mentioned that it is barely fifteen years since the development of commercial aeroplanes began, and at first the increase in their commercial speed was rather slow, 80 to 110 m.p.h. (from about 130 to 180 k.p.h. till recent times), but only a year or two ago, according to the particular country, this progress has been suddenly accelerated. In Europe a speed of 220 k.p.h. (137 m.p.h.) has been exceeded, and on certain specially-equipped American lines there are aeroplanes in service whose mean speed is 250-300 k.p.h. (155 to 190 miles per hour).

But this progress remains rather localised, and it can easily be understood that the advantages involved depend to a great extent on the nature and also the range of operation of the lines and on the volume of traffic. On very short distances, and particularly if the airports are far from the towns they serve, the gain in time on the actual journey by air is of much less relative importance than in the case of long distances.

Nevertheless, even in the case of short distances such as that which separates London from Paris, as some of us know, a gain of fifteen or thirty minutes on the air journey is not regarded with indifference by passengers.

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* Translated from the French text.

CONVERSION FACTORS.

The following conversion factors are given:—

TO CONVERT	INTO		MULTIPLY BY
Force de Cheval (C.V.)	horse-power	...	0.986
Kilogrammes/sq. m.	16/sq. ft.	...	0.205
Kilogrammetres/sec.	horse-power	...	0.01315
Kilometres	miles	...	0.621
Tonnes	tons	...	0.9842

Doubtless one may see therein a valuable testimony to the warm relations existing between two great friendly capitals, but all the same it seems to me that one may gather from it a very precise indication of the leanings of the passengers in favour of the speeding up of air transport, even in cases when the advantage appears to be slight.

Means of Increasing the Speed of Aeroplanes

The problem with which one is faced, and which consists in increasing to the maximum the speed of the commercial aeroplane over a determined distance, is subject to certain restrictions. For example, an upper limit is placed on the landing speed, and it is admitted that the ratio of the paying load to the flying weight of the aeroplane when fully loaded should not fall below a certain value, for example about 25 per cent. for distances of 500 kilometres (300 m.), and about 10 per cent. for distances of 2,000 kilometres (1,200 m.) covered at high speeds.

Finally, it is specified that the maximum speed in service corresponds only to a certain fraction of the maximum of the effective power the engine can develop, for example 60 or 70 per cent. of this maximum power, so as not to overwork the engine. We shall call that power W_n, the service power.

These conditions fix within fairly narrow limits the characteristics of the *flying weight*, *nominal power*, and *surface* of the aeroplane to be considered, as soon as one has chosen the type of aeroplane, its mode of construction, and the essential features of form of its wing unit.

Every effort of the engineer should tend to profit as much as possible by the conditions of flight, lightening of construction, and economy in aerodynamic resistances which favour the increase of speed.

Three principal means may be used in order to increase the speed of a given type of aeroplane of minimum drag; one may either increase the engine power, or the wing loading (or total weight per square metre of wing area) by reduction of the surface of the wings, or the altitude of flight.

If applied to a certain type of aeroplane separately, and to the exclusion of the others, each of these means involves, at the maximum speed range in service, the peculiar consequences which are familiar to most of you, namely:—

An increase in power leads to a reduction in the pay load.

An increase in the wing loading is advantageous only up to a certain point, and is, in particular, limited by the consideration of the minimum speed necessary for the purpose of landing, as also in certain cases in respect of the take-off.

Finally, the increase in the altitude of flight necessitates the provision of supercharging devices for the engine, as well as special cabins to keep up the air pressure. It also involves an increase in the structural weight and at the same time generally a reduction in the thermal efficiency of the engine, that is to say an increase in specific consumption, whereby the range is reduced.

Thus these three means respectively give results which militate against and limit the advantage anticipated from each of them separately.

Consequently it is advisable to use them simultaneously, by combining them judiciously, and to make every effort to extend their limits of application.

In this respect, it is known that the aim of the most recent technical improvements is precisely to facilitate the landing of aeroplanes of heavy wing loading and to develop the power of the engines at high altitude.

In passing, I should like to make some general observations on these two points.

Safety in landing does not depend only on the minimum speed in horizontal flight near the ground, but also on the maximum gliding angle at the moment

when the aeroplane is approaching the landing ground and is passing over the obstacles which surround it—in short, its ability to come to a standstill on the ground with as short a landing run as possible.

Safety in landing also certainly depends on the quality of the landing ground, the surface of which should be as smooth as that of good roads. In time to come one will doubtless be astonished at the bad state of most of our landing grounds, on which motorists could not drive at more than 50 or 60 k.p.h. (30-40 m.p.h.) without causing serious injury to their cars.

In other words, it is not only necessary to increase the lifting power of the wings, but also its aerodynamic resistance as well as the braking of the aeroplane on the ground. Thus the problem of landing is more and more bound up with the properties of braking the aeroplane in the air and also on the ground.

Braking and Lift-increasing Devices

Numerous methods have already been employed, or seriously considered, for increasing safety in the landing of aeroplanes which are becoming more and more heavily loaded, viz., wings provided with slots on the leading edge, as well as slotted ailerons (I am pleased to take this opportunity to render much merited homage to Mr. Handley Page, whose remarkable work and success has been a powerful stimulus to other research workers), pneumatic devices for high lift, upper and lower surface flaps, wheel brakes, reversible airscrews, air brakes, etc.

We also see to-day the classic wing form improved gradually by means of devices which are relatively simple and capable of causing considerable modification in its aerodynamic properties in slow flight. If to these one adds rotary wings, auxiliary or main, freely rotating or controlled, one is led to think that we are witnessing a new birth in the study of the processes of lift of flying machines, and one is justified in thinking that in a few years commercial aviation will be freed for good from the restrictions which the anxiety for safety in landing still imposes on the loading of the wings.

For my part, I am convinced that in future the airscrews which propel the aeroplane will be utilised to a great extent for giving assistance at the moment of landing, and also for lifting and braking.

Even now, in any case, wing loading of 100 to 130 kg./m.^{2} (20-27 lbs. per sq. ft.), perhaps even 150 kg./m.^{2} (30 lbs. per sq. ft.), may be contemplated for fast commercial aeroplanes equipped with suitable braking devices.

High Altitude Flight

As regards flying at high altitudes, consideration for real practical possibilities calls for certain remarks. First of all, it is necessary to make a clear distinction between the case where one does not have to take special precautions, that is to say when the crew and passengers breathe the ordinary atmosphere, and the case in which they face the inconveniences of breathing an artificial atmosphere. In the first case it is hardly possible for aeroplanes to fly at an altitude exceeding 4,000 metres (12,000 ft.); in the second case the inconveniences increase only very slightly with height, and it is then logical to attempt to fly at the greatest height. This plea is often put forward by the protagonists of so-called stratospheric aviation, certain of which claim, without restriction, that the greater the altitude the greater the speed.

As is well known, the terrestrial atmosphere above 11,000 to 12,000 metres (36,000 to 39,000 ft.) is, by common consent, called the stratosphere.

May I be permitted to show, in passing, such an absolute belief is in contradiction with the actual data relative to flight at high altitudes.

The speed of flight is given by the formula $V=\eta Wn/Ptg\phi$. Thus it is clearly seen if the relative power Wn/P is given that the speed reaches its maxi-

mum at the altitude where this speed is realised for the lift which corresponds to the best D/L ratio, that is to say to the lowest value of $tg\phi$ or the greatest of $\eta/tg\phi$.*

At this optimum altitude the aeroplane flies at the greatest speed permitted by the engines used. This *optimum altitude*, which it would evidently be disadvantageous to exceed, is not very high; at full load it would be about 11,000 metres (36,000 ft.) for the aeroplanes with which we are concerned.

This also presupposes, as I have pointed out, that the *effective* power of the engine is kept constant as far as such altitudes, in spite of the rarefaction of the surrounding air. This result can be obtained only by supercharging the engines by means of suitable compressors. For moderate altitudes these superchargers are relatively light, and the problem is already solved, or could be, in a practical way, up to 6,000 or 7,000 metres (20,000-23,000 ft.).

For higher altitudes a number of superchargers must be arranged in series, and radiators must be provided for cooling the air which has been compressed for supercharging the engine. The weight and the mechanical complication of the engine then increases fairly quickly, and the thermal efficiency of the whole decreases considerably, which results in an *increase in consumption* to the detriment of the pay load carried or the distance which can be covered in a non-stop flight.

If one takes into account the inevitable inconveniences, without even mentioning certain problems which are still to be solved in connection with good functioning of the airscrews, which should be of variable pitch or, better still, governed by changes in speed—the optimum altitude for which we have just determined an upper limit, is lowered very considerably and can hardly exceed about 8,000 metres (26,000 ft.) for the fast aeroplanes which we are considering.

I do not wish to say that one day it will not be desirable to fly at 15,000 or 20,000 metres (50,000-65,000 ft.), but we are still far from this stage until new engines and new airscrews are evolved. Perhaps these future aeroplanes will resemble winged rockets, but at the moment I shall not deal with these problems.

I shall not consider here the future of the helicopter, in which I believe firmly, but only the possibility of flight with aeroplanes provided with engines similar to our present engines and flying at lower altitudes, say, 8,000 metres.

One may ask oneself whether it is not sufficient to remain below 4,000 metres, where one can avoid the complication of special clothes and breathing apparatus or, *a fortiori*, that of cabins with an artificial atmosphere. I shall answer this question in drawing the conclusion that flight above 16,400 ft. (5,000 m.) offers no particular advantages.

If one considers this solution in the immediate stage of development of the commercial aeroplane, one is led to consider that only a very moderate supercharging of the engines now in use would be necessary. We assume that, in order to prolong their life, these engines would be used in normal flight at only about 70 per cent. of their maximum effective power, so that a reduction of 30 per cent. of this maximum power can be accepted, from the mere fact of the rarefaction of the air at a high altitude. No supercharging is necessary so long as the altitude of flight does not exceed about 3,000 metres (10,000 ft.).

In fact, in order to ensure a good volumetric efficiency of the engines, the speeds of which are increasing in order to obtain the desired lightness, mixers or compressors must be used in commercial aviation. (The problem is quite different as regards military aviation.)

To sum up, and keeping to practical politics, it seems to me that the fast commercial aeroplane in the very near future will have a heavy wing loading 20-30 lbs. per sq. ft. (100-150 kg./m.^{2} for example), means for increasing the lift considerably, air brakes and ground brakes, the use of powerful and light

* We call D/L ratio the relative drag $Cx/Cz=tg\phi$, the angle ϕ being formed by the aerodynamic resultant and the perpendicular to the path of flight. η=airscrew efficiency.

engines which are moderately supercharged and have a low specific consumption, the frequent use of altitudes of flight not exceeding about 4,000 metres, and finally the adoption of cabins which are as comfortable as possible, heated, and if necessary supplied with oxygen.

Let us note in passing that the commercial aeroplane, in thus turning towards the development of speed (which is its outstanding quality as compared with all other means of transport), is characterised more and more by a very considerable excess of power* which overcomes any difficulty connected with the problem of taking off, as well as that of flight when one engine of a multi-engine aeroplane has stopped.

Speeds Attainable

Now let us see what commercial speeds can be reasonably contemplated as attainable under the most favourable conditions.

In order that the problem may be considered in an up-to-date and sufficiently comprehensive way, I shall consider the case of *land* aeroplanes of a weight of about 8 to 15 tonnes, provided with two, three or four engines, and intended normally to cover distances of 800 to 2,000 kilometres (500-1,200 m.) with a contrary wind of 50 k.p.h. (30 m.p.h.).

It will be assumed that the aeroplane and its power plants are as well streamlined as possible, that the aeroplane is provided with a retractable undercarriage or an undercarriage offering minimum resistance, and finally that the wing unit has an aspect ratio of 8, the wing loading at the take-off being, for example, 130 km./m.^{2} (26 lbs. per sq. ft.).

The speed attainable certainly depends on the conditions of flight, the altitude and range of operation, and the power installed, that is to say on the part of the total weight one can devote to this installation.

The partial weight P_m is obtained by deducting from the total weight at the start P, the sum of all the other partial weights—structure (P_p), crew and equipment (P_e), paying load and fixtures (P_u), fuel and oil for the engines (P_c), the weight P_c depending only on the range of operation on the total weight and relative resistance $tg\phi$ at the speed V chosen.

$$P_m = P - P_p - P_e - P_u - P_c.$$

$$\text{That is } P_m/P = 1 - P_p/P - P_e/P - P_u/P - P_c/P.$$

The method of analysis and representation I am going to indicate allows one to calculate fairly easily the speed as a function of the conditions of flight.

On a curve diagram which represents, as an ordinate, the distribution of the weights as a function of the speed is plotted against altitude.

1. We start from the axis of the abscissæ and put down successively the relative weights P_m/P of the power plant, and the relative weight P_c/P of the fuel and tanks. These two depend on the speed, the range of operation, the altitude of flight, and on the conditions of running the engine with relations I shall indicate later.

2. Starting from the ordinate 100 per cent., corresponding to the total weight, and by deducting from it in turn the relative weight P_p/P of the structure and P_e/P of the crew and equipment, these two elements are, for a given family of aeroplanes, independent of the speed and range of operation. The ordinate obtained is then constant or given.

The difference of ordinates between the curves representing the sum $(P_m/P + P_c/P)$ and the horizontal representing $(1 - P_p/P - P_e/P)$ then measures the relative weight P_u/P available for the useful load and the equipment.

* It may be taken for granted that a modern high-speed moderated supercharged aeroplane will weigh approximately 9 lbs. (4 kg.) per h.p., or 13 lbs. (6 kg.) for normal service h.p. This figure increases to 16.5 lbs. (7.5 k.g.) for highly supercharged engines and aeroplanes with light cabins.

On the diagram thus plotted, the variation of this capacity of load with the speed is clear, and it is easy to study the effect of various parts of the problem on the commercial speed of the aeroplane.

Let us now consider, for a modern aeroplane, how one can evaluate the various elements which have just been enumerated.

(*a*) *Weight of the Power Plant.*

This can be estimated by multiplying the power used by the weight per h.p.* of the engine (q). For example, if the h.p. used is taken as 70 per cent. of the maximum or nominal power of the engine, one may assume that the utilised h.p., for good modern power units and altitudes included between 0 and 4,000 metres, represents a net weight of 1.3 kg. per h.p. (2.9 lbs.).

As regards the utilised power, it is the produce of the total weight P multiplied by the speed V and the L/D ratio $tg\phi = Cx/Cz$, itself divided by the airscrew efficiency η which I shall assume, on an average, to be equal to 75 per cent.

$$P_m/P = \left(\frac{1.3\,\text{kg.}}{75}\right)\left(\frac{V}{\eta}\right) tg\phi.$$

There remains to be estimated the D/L ratio.

It depends on the minimum resistance $C''x_0$ of the whole aeroplane, and on the lift Cz, in accordance with the law that expresses the polar of the aeroplane, and which, for a very wide range of speed, is represented very conveniently by a parabola. The state of lift is itself a function according to the definition of the lift, of the wing loading P/S, of the altitude of flight, and the speed.

The minimum resistance $C''x_0$ of the complete aeroplane includes a part due to the wing unit and to tail unit and part which only depends on the type of the wing and of its section, and which I shall estimate at 0.015 (δ) for monoplane wings, and a part due to drag—that is to say to the body, to the engine nacelle, and to the undercarriage or floats. The coefficient of drag depends, at the same time, on the weight of the aeroplane and the wing loading.

Without going into more details I shall assume that the present technical data allow us to adopt the following simple formula for the calculation of $C'x_0$ in the case we are considering, that is to say for aeroplanes with a high degree of fineness:—

$$C'x_0 = 0.015 + 0.002\,(P/S)\,P^{-1/3}$$

According to this formula, the minimum resistance of an aeroplane of eight tonnes with a wing loading of 100 kg./m.^{2} would be 0.025, and that of an aeroplane of 12 tonnes with a wing loading of 120 kg./m.^{2} would be 0.0263. These figures are sufficiently suitable for my explanation, and certainly the above formula could be modified in order to adapt it more closely to aeroplanes which would present qualities different from those assumed here.

It is certain that better figures can be obtained in future, particularly when the engines and their cooling devices, for large aeroplanes, can be completely enclosed in the fuselage or in the wings. In this case $C'x_0$ can be less than 0.020.

By adding to this minimum resistance of the complete aeroplane the induced resistance, which is a function of the utilised lift and the aspect ratio of the wing, and then dividing by the wing loading, one obtains the D/L ratio which is to be estimated. The formula giving the ratio is:—

$$tg\phi = \frac{16(P/S)}{\delta V^2} + \frac{Cx_0\delta V^2}{16P/S} + \frac{0.002P^{-1/3}\delta V^2}{16}$$

δ being the relative density of the altitude under consideration.

Thus one has all the elements necessary for calculating the relative weight P_m/P of the power unit as a function of the speed V for an aeroplane of which one is given the aerodynamic characteristics of the wings, the wing loading, the

* French h.p. (C.V.) is referred to throughout.

total weight, the altitude of flight, and finally the net weight of the horse-power effectively utilised:—

$$P_m/P = (1.3V/75)\,(tg\phi/\eta)$$
(V in metre/seconds).

(*b*) *Relative Weight of Fuel and Tanks.*

As is known, this relative weight P_c/P is given for a range of operation E (in km.), the speed of flight V (in m./sec.), a contrary wind v (in m./sec.), a specific consumption of the engines of 0.275 kilogrammes of fuel and oil per effective horse-power hour 0.6 lb./h.p./h., and an increase of 5 per cent. for taking into account the weight of the tank, by the well-known formula:—

$$\text{Log}\ (1-P_c/P)^{-1} = tg\phi \frac{0.275\ EV/(V-v)}{622\eta} \times 1.05$$

(*c*) *Relative Weight of the Structure, and of the Crew and Equipment.*

As is known, the relative weight of the structure varies for a given type of aeroplane with the dimensions and weight of the aeroplane. If this weight remains between two fairly close limits, this variation is small; it increases with the dimensions, and therefore with the weight.

Under the same conditions, the weight of the crew and the equipment of the aeroplane represents a total which is nearly constant, so that its relation to the total weight decreases when the weight increases, and this decrease compensates to a certain point the corresponding increase in relative weight of the structure.

If the total weight is varied between 8 and 12 tonnes, for example, for the sum of the relative weight in question, one may assume an almost constant value of 34 *to* 40 *per cent.** for the sum $(P_p+P_e)/P$, according to the care taken in design, for a land aeroplane, and slightly more for a seaplane, and still more for an amphibian.

Moreover, it will be possible to reduce these figures in the future, not only in consequence of progress in construction, but also in order to take into account the fact that for aeroplanes, for example, launched by means of a catapult, one will doubtless be able to allow a certain overload at the moment of departure, the reduction in the safety factor then no longer having the drawbacks which it would present if the take-off took place directly from the ground or from the water.

For land aeroplanes, therefore, one can contemplate a relative structure weight of 30 per cent. at the moment of departure. It must be pointed out that the weight of the bare structure does not include the pilot's cockpit, nor the windows, doors, panels, ceilings and seats, interior cabin covering, the weight of which will be included in the equipment corresponding to the number of passengers and the paying load carried.

Moreover, the diagram shown in Fig. 1, which I present by way of an example, renders it possible to give to the relative weight in question any value one considers reasonable, and to examine the influence of the range of operation, of the constructional weight, and the paying load capacity, on the speed of flight.

This diagram relates to an aeroplane of 10 tonnes, aspect ratio 8, having a wing loading of 100 or 130 kg./m.^{2}, capable of travelling 1,000 and 3,000 kilometres at an altitude of 2,200 metres, against a wind of 50 k.p.h., with all the data already assumed for the weight and consumption of the engines. According to the formula given above, for this aeroplane the minimum drag will be 0.0243 or 0.0271, according to whether the wing loading is 100 or 130 kg./m.^{2}

This diagram clearly shows the relation between the speed, the range of operation, and the paying load capacity.

* These figures apply to aeroplanes built to I.C.A.N. safety factors.

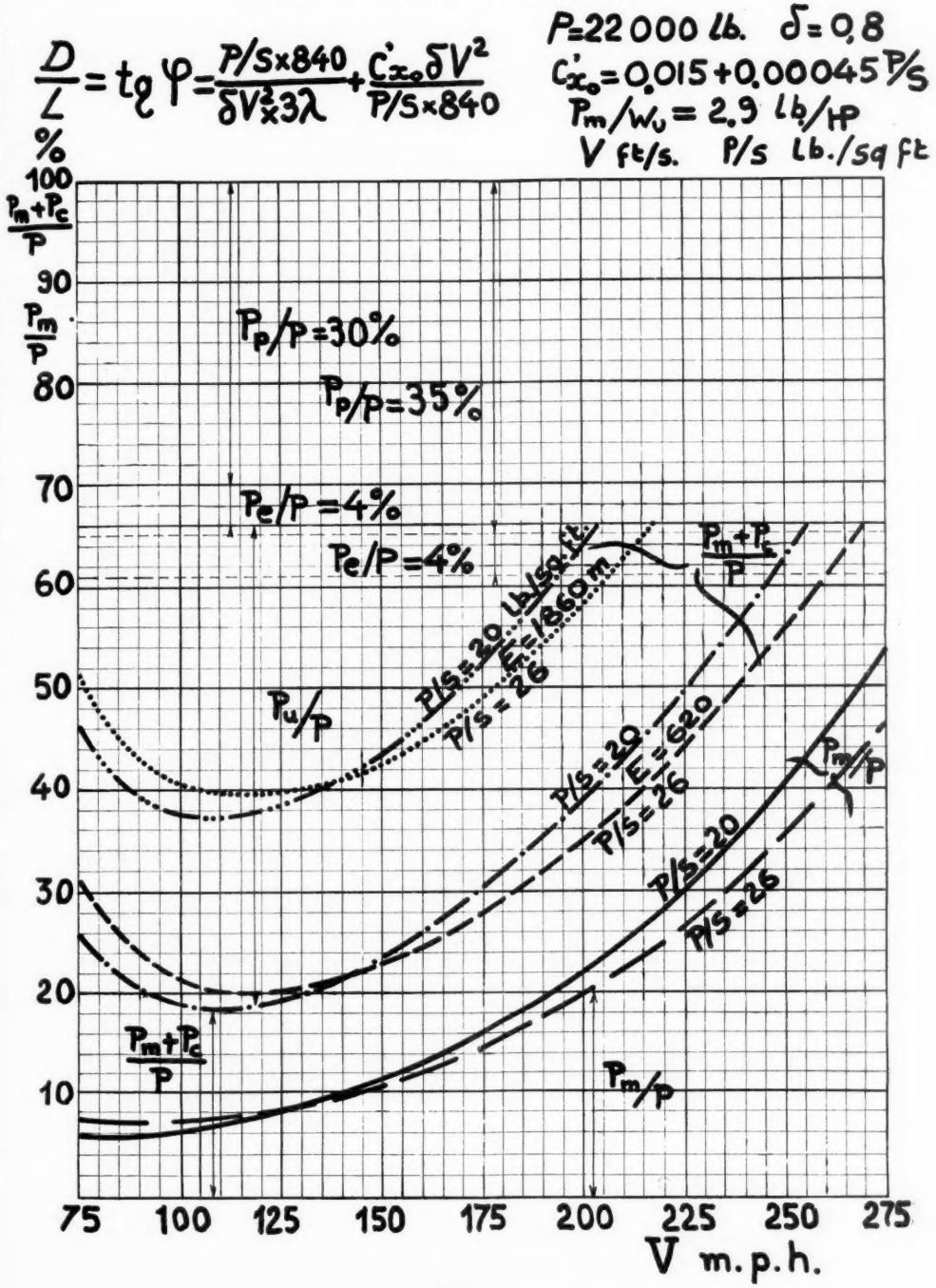

D/L = tg φ = P/S×840 / δV²×3λ + C'x₀δV² / P/S×840
P=22 000 lb. δ=0,8
C'x₀=0,015+0,00045 P/S
Pm/Wu = 2,9 lb/HP
V ft/s. P/S lb./sq ft
%
100
90
80
70
60
50
40
30
20
10
Pm+Pc / P
Pm/P
Pp/P=30%
Pp/P=35%
Pe/P=4%
Pe/P=4%
Pu/P
P/S=20 lb/sq ft
P/S=26
E=1860 m.
E=620
P/S=20
P/S=26
P/S=20
P/S=26
Pm+Pc / P
Pm/P
75
100
125
150
175
200
225
250
275
V m.p.h.

FIG. 1.

The application of these very simple processes of analysis leads to the conclusion that, in the conditions under which we are placed, it is hardly possible to contemplate commercial speeds exceeding 400 to 450 k.p.h. for ranges of operation of 1,000 kilometres, and 320 to 350 k.p.h. for ranges of operation of 3,000 k.m., namely, by carrying paying loads reduced to the minimum and by flying at altitudes varying from 3,000 to 5,000 m. These speeds would be further reduced for greater useful loads.

One could do better only by extending the limits assumed above for the wing loading and for the altitude of flight, or by increasing the useful power of the engine, that is to say by relying upon lesser weights per h.p. or by using engines of smaller specific consumption. The assumption of 275 gr. (0.6 lb.) is rather high, but relates to engines provided with moderate supercharging, and to carburettors regulated for a prolonged service.

Influence on the Cost of Transport

It is not sufficient that commercial aeroplanes should be capable of attaining speed of the order of magnitude just determined—which other means of locomotion cannot attain—but it is also necessary that the cost should not be excessive.

The study of the effect of speed on the cost of air transport is of prime importance, because it is essential to know to what extent the increase in speed can be lucrative in a given state of the economic world.

Indeed, this increase in speed influences both the receipts and expenses.

As regards the *receipts*, increase in speed can cause an increase in the flow of traffic on existing air lines, or can bring new lines into existence.

But the question of successful traffic operations is a matter on which one can only conjecture, and on which I shall refrain from dwelling at any length.

On the other hand, as regards the *expenses*, the cost of air transport can always be estimated in advance with sufficient accuracy, at least relative, if one keeps a sufficiently detailed and exact account of all the details, by extrapolating judiciously the data of the experience acquired.

One can estimate the cost of the tonne/kilometre offered by dividing the sum of the expenses per flying hour by the speed per hour and by the tonnage of the transportable freight.*

The total of the expenses per hour includes very varied elements which may be grouped under the following principal headings:—

(*a*) Redemption and upkeep of the structure.
(*b*) Redemption and upkeep of the engines.
(*c*) Navigating personnel.
(*d*) Fuel and lubricants.
(*e*) Ground service, and management of the airports.
(*f*) General expenses of administrative services and commercial services.

The speed of flight has very different effects on the various elements.

It should first of all be remembered that, the faster the aeroplanes, the longer the distance they can cover during the normal duration of their daily use and during the daily working hours of the crew. By thus helping the *use* of the material and the crew, the speed tends to permit a reduction in the number of the aeroplanes in the air fleet and also of the navigating personnel, and also in a reduction of the corresponding general expenses. This has been verified with ships.

On the other hand, if one bases one's views upon this principle, which has been fairly well verified by actual experience, that the depreciation and the

* This formula will be found in its most recent form in a communication presented by the author in 1932 to the American Society of Mechanical Engineers, the French text of which has been published in No. 1 of "Science Aérienne," July-August, 1932 (Ballière, Paris).

periodical overhauling of the structure and engines should be determined by the total time in effective flight service, it is evident that the corresponding expenses per flying hour vary, especially with the weight of the aeroplanes and the power of their engines, but do not depend directly on the speed of flight.

It is the same with the hourly expenses of navigating personnel, or of fuel or lubricants.

The latter, however, as those of depreciation and upkeep of the engines, are proportional to the power of the engines, and the latter is bound up with the speed.

But it should be noted that this is proportional to the simple product of the speed of flight and the corresponding aspect ratio. If the latter can be maintained constant while causing the speed to increase—and one tends to attain this by increasing the wing loading and the altitude of flight up to acceptable limits—the power would increase only as the speed, as well as the corresponding hourly expenses, so that these same expenses, divided by the speed per hour in relation to the kilometre travelled, would remain constant.

This is to the advantage of the aeroplane, and is a fact the importance of which cannot be too strongly emphasised and one which distinguishes the aeroplane from all other means of transport. For the latter, in fact, the expenses per kilometre relative to the power in question increases very rapidly with the speed, and, besides, the latter remains very far behind that which only the aeroplane can attain.

As regards the operational expenses of the airports and the general administrative and commercial expenses, they depend more on the extent of the system served and on the tonne/kilometre offered on the whole of this system than on the individual characteristics of weight, power, and speed of the aeroplanes employed. Nevertheless, the speed is a factor when the total of these expenses is added to the flying hour, because the kilometric tonnage carried by each aeroplane in a flying hour depends on the speed in proportion to the journey per hour that it symbolises, and on the reduction in the relative capacity of transport which the development of power involves.

As I have already indicated, factors in the denominator of our formula are:

On the one hand the practical speed per hour, the increase in which is thus directly favourable to the cost; on the other hand, the weight of the transportable freight, which results from the difference between the total weight of the aeroplane and the partial weights of the structure, the engines, the supplies, the crew and the equipment. It is clear that it is principally the weight of the engines and that of the fuel that hinders an increase in speed. But the weight of the engine increases only in proportion with the power, itself proportional only to the product $PVtg\phi$, and the weight of the supplies of fuel increases for a given range of operation with a zero wind only in like manner as the D/L ratio. Moreover, for this partial weight, the relative increase in fuel to be provided for compensating for contrary winds diminishes when the air speed of the aeroplane increases. The curves of our diagram clearly show these conclusions.

I will add that the practical speed per hour of which I have spoken is always less, on an average and because of the influence of the winds, than the actual speed of the aeroplane in relation to the atmosphere. Now, the more one increases the air speed of the aeroplane, the more the mean influence of the winds encountered decreases in relative value, so that one finds here an economic advantage correlative of the advantage of working contributed to the regularity of the service.

Without entering into a more detailed analysis of these influences, some favourable, others unfavourable, of speed on the cost, an analysis I have already presented elsewhere, these summary indications suffice, it seems to me, to make it clear that the cost of speed in air transport can vary only in rather a slight manner when the rapidity of transport is progressively increased.

In fact, the calculation shows this very clearly in numerous cases and within a very wide range of speeds.

By way of an indication, here are the results of a calculation of this sort made in connection with air transport service maintained by fast and modern aeroplanes such as those defined above.

Let us suppose an air line network, including seven airway sections or stages, of 1,050 m. (1,700 km.), three main airports and four intermediate airports, and served by aeroplanes of the type indicated, the latter weighing 10 tonnes at the start, wing loading 130 kg./m.^{2}, and flying at an average altitude of 4,000 metres, the aeroplane being used near to its D/L ratio and flying at 240 k.p.h., that is to say at an economic speed, or at a much greater speed—let us say 360 k.p.h.

For a slow aeroplane, the lift used is then 0.7, the D/L ratio 6.8 per cent., and, with an airscrew efficiency of 75 per cent., the effective power 800 h.p.

For a fast aeroplane the lift used is 0.31, the D/L ratio 10 per cent., and the effective power 1,770 h.p.

Thus one compares the two modes of working with fast and slow aeroplanes, and a park of material including six aeroplanes—two of which are in regular service, one being overhauled, and three in reserve—and 24 engines, five of which are in supplementary reserve distributed between the seven airports of the network.

In fact, for slow aeroplanes, the power to be installed is not only $1/0.7 = 1.43$ times the power effectively utilised, since the latter is limited by convention to 70 per cent. at most of the maximum power. Because, in order to satisfy the requirements of the certificate of airworthiness in respect of the conditions of take-off, it is necessary to have a larger surplus of power and to install twice the power necessary for economical flight—let us say 1,600 h.p. For fast aeroplanes, on the other hand, it suffices to install 1.43 times the power utilised—let us say 2,540 h.p.

By reckoning the weight of nominal h.p. at 1 kg. (2.2 lbs.)* one can draw up the following estimates of weight, in which we assume a particularly light structure weight which implies a fairly lightened construction of these land aeroplanes. If necessary, there is a temporary and moderate overloading at the start.

	Slow aeroplane. Kg.	Fast aeroplane. Kg.
Bare structure weight	3,000	3,000
Power plants	1,600	2,540
Tanks and supplies (distance 1,700 k.m., contrary wind, 50 k.p.h.)	1,850	2,420
Crew and equipment	400	400
Fixtures	1,050	540
Paying load	2,100	1,100
Total weight at the start ...	10,000	10,000

From this table one sees that the slow aeroplane can carry a pay load 90 per cent. higher than that carried by the fast aeroplane, the speed of which, however, is 50 per cent. higher.

But our calculation slightly favours the first in respect of fine D/L ratios, because one has attributed to it the same drag as the second, although its fuselage should be considerably larger by reason of the greater weight of its pay load. However, I shall refrain from making the slight modification in favour of the fast aeroplane which this remark would justify.

* The diagrams have been calculated with a smaller weight of the power plant: 2 lbs. (0.91 kg.) per rated h.p. (2.9 lbs., 1.3 kg. per service h.p.).

Finally, one will assume that the fast aeroplane will make two journeys in a day, each necessitating a flight of about five hours, although the slow aeroplane will be able to make only one journey daily in eight to nine hours. Thus the fast aeroplanes ensure a traffic more than double that of the slow aeroplanes, the loading capacity of which is superior by 90 per cent., but the distance covered daily half as much.

Thus with the same park of material one can ensure increased traffic with fast aeroplanes.

The part of the general expenses of all kinds, including the expenses in connection with the runway and tarmac and the airport expenses, in the cost of the tonne/kilometre offered—which part remains very high in air transport* by reason of the still somewhat restricted traffic and the great length of the lines served—may then be considered substantially identical in both cases, and consequently they will be excluded from the following comparative estimates.

According to reasonable estimates—which are also slightly optimistic, in order to give credit to what the near future may produce—regarding the conditions of purchase price, duration of existence, and the maintenance costs of the material, and also cost of fuel and of the crew (E), one can draw up the following table—in rounded off figures—of the expense per flying hour, not including general expenses of any kind.

Expenses per hour.	Slow aeroplane. (V=240 km./h.) Frs.	Fast aeroplane. (V=360 km./h.) Frs.
Depreciation and general maintenance of the structure	815	815
Depreciation and general maintenance of engines	515	810
Fuel and lubrication	600	1,300
Crew	650	650
	2,580	3,575

I assume, for example, the reserve material depreciates in five years, the structures or the engines in service respectively depreciate in 4,000 and in 2,000 hours, overhauled after 1,000 and after 500 hours, the specific price of the structures 150 frs. per kg. of the total weight of the aeroplane, that of the engines 300 frs. per nominal h.p., that of the fuel and lubricants 3 fr./kg., the cost of overhauling equal to 18 per cent. or 20 per cent. of the cost price for a structure or an engine, etc.

In order to pass from these expenses per hour to the kilometre/tonne offered, it is necessary to divide the above totals by the practical speed per hour and by the weight offered.

The practical speed can be estimated at 90 per cent. of the air speed of the slow aeroplane, let us say 216 k.p.m., and at 95 per cent. of this speed for the fast aeroplane, let us say 340 k.p.h. As regards the weight offered, they are 2.1 and 1.1 tons respectively.

The costs of the kilometric tonne offered, but not including the general expenses of any nature which are substantially the same in the two cases compared, thus amount respectively to:—

-5.70 fr./t.km. for the slow aeroplane,
-9.60 fr./t. km. for the fast aeroplane.

By estimating at 3 fr./t. km. the general items regarded as identical in both cases, expenses of any nature not evaluated above, as well as expenses necessitated by the hazards and incidents of operation—an estimate that I deduce

* In a large number of cases this part actually represents 25 to 40 per cent. of the total expenses.

from the analysis of the actual results of operation in sufficiently comparable conditions—the total cost of the t.km. offered comes to:—

8.70 fr. for the slow aeroplane.
12.60 fr. for the fast aeroplane.

From this example one sees that an increase of 58 per cent. of the practical commercial speed, which comes to 216 to 340 k.p.h., involves an increase of only 45 per cent. of the cost of the kilometric tonne offered.

The double advantage of rapidity and of regularity obtained by reduction of the effect of the wind on the practical commercial speed thus procured, opens the way on the one hand to a justified increase in the transport tariff, and on the other hand to a development of traffic which ameliorates the mean utilisation of the fast aeroplanes.

It does not appear to me to be exaggerated to think that these two causes of increase in the kilometric receipts can greatly exceed the increase in cost of the unit of transport offered to users.

In other words, one may conclude without being over bold that such an important increase in the speed of transport should be remunerative.

It will be noted that the cost which I have just estimated—12.60 fr./t. km. —for a commercial aeroplane of 10 tonnes flying at 360 k.p.m. over distances of 1,700 km., is certainly less than that of many of the present commercial aeroplanes the speed of which, however, does not exceed 200 to 250 k.p.h. This is evidently due to the good D/L ratio (10 per cent.) attributed above to the fast aeroplane which I have considered, as well as to the relative lightness of the structure and of the engines. In this respect I must acknowledge that my hypothesis may appear to be optimistic, but I do not think that it goes far beyond what one may expect of the present rate of technical progress in aviation.

By way of a simple indication, I shall cite the result of the forecast one may make in a case where the anticipation is certainly much more remote. I allude to flight at an altitude necessitating a considerable supercharging of the engines and the use of cabins with artificial atmosphere.

Let us retain all the preceding data relative to the type of aeroplane and to the service ensured, but suppose that the mean altitude of flight be carried out at 8,000 metres instead of merely 4,000 metres.

In this case our aeroplane of 10 tonnes, load 130 kg./m.^{2}, and flying at 8,000 metres at the same lift ratio as at 4,000 metres, at a speed of 360 k.p.h., will have a speed of 450 k.p.h. for an effective power of 2,220 h.p. and a rated power of 3,180 h.p. instead of 2,540 h.p.

If one reckons on an increase of 20 per cent. of the specific weight of the nominal h.p. and on an increase in the specific consumption for the considerably supercharged engines flying at 8,000 metres, the estimate of weight is composed of the following items:—

Structure	3,000 kg.
Power Plant	3,810 ,,
Tanks and fuel	2,660 ,,
Total	9,470 ,,

The total of which leaves only 530 kg. available for the crew, the fittings, and the freight. As one should add to the 400 kg. of the crew and its ordinary equipment a supplementary weight of 150 to 200 kg., at least, for special equipment and fittings for the flight at 8,000 metres, it is clear that the useful transport capacity of our aeroplane of 10 tonnes is then reduced to nil. One gathers from this example how very deceptive can be the mirage of economy in air transport at high speed and at a great altitude.

If in the flight at 8,000 metres one limits oneself to a speed of 360 k.p.h., the same aeroplane would then function with a better D/L ratio than at 4,000 metres, and therefore with less power, but with engines of higher specific weight.

In this case—which is interesting to compare with that of flight at the same speed of 360 k.p.h., but at only 4,000 metres—the same estimate of weight would be the following:—

	Flight at 8,000 m. (V=360 k.p.h.) Kg.	Flight at 4,000 m. (V=360 k.p.h.) Kg.
Structure	3,000	3,000
Power unit (1,960 h.p. at 1.2 kg./h.p.)	2,350	2,540
Tanks and supplies (distance 1,700 km., contrary wind, 50 k.p.h.)	2,100	2,420
Crew and ordinary equipment	400	400
Special high altitude equipment	200	—
Freight and passengers	300	—
Ordinary fittings for the freight	520	540
Pay load	1,130	1,100
Total ...	10,000	10,000

The gains in engine and fuel weight are balanced by the weight of the special high altitude equipment.

The pay load therefore remains substantially the same as in the case of flight at 4,000 metres and at the same speed. As regards the expense per hour referred to above, it is reduced only for the consumption of fuel (about 13 per cent.) although it increases for the depreciation and upkeep of the structure and the engines, especially the latter, by reason of the increase in price of this more complex material. After all, the examination of these probable figures shows that these influences can at the most be compensated in such a way that the cost of the kilometric tonne offered remains substantially the same in both cases.

It seems to me, therefore, that one can arrive at only a negative conclusion as regards the benefit to be gained by attaining speeds of 360 k.p.m. at 8,000 metres, rather than at 4,000 metres, all the more so as at moderate altitudes of this order one escapes all the difficulties associated with flight in rarefied atmosphere with regard to the engines, the airscrews, the crew and the passengers.

This conclusion has, of course, only one actual value, and it is by no means claimed that, in a probably rather far distant future, the still doubtful benefit of flight at a very high altitude will not become reality.

Indeed, it would already be a very great progress if the aeroplanes used on the Indian, African, and South American routes could attain speeds of approximately 320 k.p.h. by flying between 3,500 and 5,000 metres.

I have especially wished to show that it is very possible to attain these speeds without any detrimental effect on commercial air transport enterprises and I even think that the increased revenue which may be expected will make such an operation more advantageous from the financial point of view.

It is in this way that one must work, without unjustifiable fear of high speeds.

I shall now close with one further remark. By the development of the engine power that it necessitates, air transport at high speed and with a long range of operation places the consumption per kilometre in the foreground, and thus confers a technical and economic importance to the production of engines which, while being lighter and of great endurance and consuming a low-priced fuel of low inflammability such as commonly used, will lead to a great reduction in specific consumption.

Everyone knows that these multiple qualities cannot be easily reconciled, but they constitute an aggregate of objectives which the technicians who devote their efforts to the development of the aero engine are striving to attain.

When the present specific consumption of 0.6 lb./h.p. (275 gr./h.p.), on which the calculations in this paper are based, decreases to less than 0.44 lb. (200 gr.) it is obvious that it will be possible to carry greater useful loads at higher speeds or over greater distances.

I conclude on the affirmation that it is along the lines of greater speeds and increased ranges that work should be carried on, without unjustifiable fear of the possible dangers and the cost of great speeds. Thus commercial aviation will reach its full development throughout the world.

Discussion

Mr. F. Handley Page: They had all learned that this country was far behind every other country in the matter of speed of civil aircraft—due to a variety of causes, none of which were attributable to the particular individual who made the complaint! Perhaps the factor having the greatest bearing on slow speed, particularly on eastern routes, was lack of ground organisation, because at the present time, if one flew by the normal route from this country to the East, one found that the machines flew only by day and they mostly remained on the ground at night. Therefore, the greatest increase they could effect in speed on the imperial routes would be by flying at night as well as by day; by that means they could effect an increase of speed and a decrease of time of more than 100 per cent. One could not achieve that result by improving the aeroplane, and therefore, when looking for a cause of their present slow speed on air routes he would at least be in the fashion by saying that the matter had very little to do with the aeroplane and had a great deal to do with the ground organisation.

But when one looked at the figures given by M. Breguet, one was impressed by the fact that if they were going to operate an air transport line and wanted to choose the speed at which the machines were to fly, the choice would be made for one of two reasons. In the first place, there was the economic reason, which meant determining the best speed at which to fly in order to make the air transport undertaking a success. One had to consider, not merely the costs of running the line or the possible receipts, but the net profit that would arise from operating it as a commercial undertaking, although, of course, that involved the costs of operation and the receipts. Looking at the matter merely from the point of view of the costs of operation, M. Breguet's curves had shown that the speed adopted would be probably somewhere about 130 or 140 m.p.h. for the normal stages which an air transport line would take—and that was about the speed which Major Green had arrived at in a very much disputed paper he had presented to the Society a few months previously. But from the general economic point of view one was not sure that a speed of 130 or 140 m.p.h. was necessarily the best for machines operating an air line, because it was extremely doubtful that they could so alter people's minds that they would want air transport unless they could afford them a very big increase of speed over that which was possible by utilising other means of transport. It was probable, therefore, from the point of view of attracting greater receipts, even at the expense of a little increase in running costs, they should adopt higher speeds, as M. Breguet had indicated in the paper; probably they should adopt speeds of the order of 175 m.p.h.

The second reason which might be considered in determining speed of flying, and one which had nothing to do with commercial aircraft as such, was that which might be termed "national prestige." If the Dutch were going to fly to the East at 175 m.p.h., they must fly at 200 m.p.h.; if at 200 m.p.h., they must fly at 225 m.p.h.; therefore, in this twentieth century, they must reproduce the old competition between the Dutch and the English for commercial supremacy,

this time in the air instead of on the sea. But, after all, Mr. Handley Page believed they should come to the conclusion, very much as various Governments of the world had come to the conclusion in regard to the Schneider Trophy contest, that it cost a tremendous lot of money and they were not quite sure what results they achieved in the end. Probably the Director of Scientific Research gained some valuable data for his department, as would also the Director of Technical Development, and perhaps the aircraft manufacturer benefited. But one thing was certain—the public paid. It would be imagined that if a lot of money were to be poured out for air transport under the compulsion of national prestige merely, and not from the point of view of making the proposition an economic one in the long run, the taxpayers would turn round and bite all the aircraft people; so that they must be sure that they did not ask too much of them. It therefore behoved them to study the interesting conclusions that M. Breguet had arrived at in his paper, to realise that there was a limit beyond which it did not pay them to go, and that it probably paid them to go a little less far.

Major R. H. Mayo (Fellow): M. Breguet's remarks on high altitude flying were both interesting and important. He put forward a figure for the optimum height for commercial aircraft, namely, about 4,000 metres, which was based not merely on present day practice but on M. Breguet's anticipation of probable future developments. This figure is about the maximum height which is practicable for passenger transport at the present time, but it is very much lower than the exaggerated altitudes about which there has been so much talk in the last few years. M. Breguet had, if he were permitted to say so, done considerable service to practical aviation by bringing the so-called stratosphere down to earth!

He would not attempt to comment on the general method of analysis put forward by M. Breguet, as he did not consider that one would be justified in doing so without careful study. The method was certainly one of great interest, and it brought out clearly the rapid reduction of capacity to carry paying load as the cruising speed was increased. It was evident that the numerical results reached must depend to a very great extent on the particular assumptions made, and it would not be fair to M. Breguet to attach undue importance to the numerical conclusions which he had reached.

With regard to the application of the method to air transport, he felt sure M. Breguet would agree that the items comprising the total operating expenses were of a very variable nature, and that variation in individual items might affect the final conclusions very materially. For instance, the cost of fuel varied to an enormous extent in different parts of the world, and when one considered the importance of this item one saw that it might very materially affect the final conclusions as to speed. M. Breguet took the cost of fuel and lubricants as three francs a kilogramme, and it would be seen that even on this basis the item for fuel and lubrication was a very important one in the case of the fast aircraft. If the cost of fuel were materially increased, the cost of operating the fast aircraft would rise to a prohibitive extent. In other words, it might pay to design for high speed in countries where fuel is cheap, but it may be hopelessly uneconomic in countries where fuel is costly.

In M. Breguet's direct comparison between the slower and the faster aircraft, it appeared to him that he had been a little hard on the slower aircraft, particularly in the matter of power required for take-off. This was perhaps due to the fact that he had assumed the same wing loading in each case. It was clear, however, from the curves in Fig. 1 that the higher wing loading is of no advantage to the slower aircraft, and if a lighter wing loading were employed it would not be necessary to saddle this aircraft with the disadvantage of such large and heavy engines. This would show up the slower aircraft to greater advantage in the matter of paying load.

Again, in the allocation of load between net paying load and fixtures, M. Breguet attributed a very high proportion to fixtures—approximately one-third of the total load. A lower proportion for fixtures would have shown up the slower aircraft more favourably in the matter of paying load. In actual practice many of the fixtures had to be carried in any case, so that in this respect again the comparison was not quite fair to the slower aircraft.

He was struck by the rather unusual range, namely, 1,700 kms. or 1,050 miles, which M. Breguet took as a basis for the comparison. It appeared to him that that was about the most favourable range that could be chosen to show up the faster aircraft to advantage. It resulted in the conclusion that the faster aircraft would be able to make two journeys in a day, whereas the slower aircraft would only be able to make one journey. That conclusion, of course, depended on the assumption that night flying was impossible, but he thought if one were looking ahead one had to assume that night flying would in fact become regular practice. If M. Breguet had taken a range of, say, 850 kms. it would have been found that in daylight only the slower machine would have been able to make one round trip and the faster machine 1½ round trips. With night flying, the slower machine would be able to make three round trips and the faster machine four round trips. In either case the final result as to earning capacity machine would be about 3½ times that of the faster machine.

Again, if M. Breguet had taken a 50 per cent. greater range, namely, 2,550 kms., then it would have been found that even on his assumption as to the weight of fixtures, the net paying load of the slower machine would be approximately five times as much as that of the faster machine. Assuming night flying, the slower machine would be able to make one round trip in the 24 hours and the faster machine 1½ round trips. Thus the earning capacity of the slower machine would be about 3½ times that of the faster machine.

He did not raise those points in any spirit of contention or because he failed to realise the obvious advantages of high speed, but merely to bring out the great importance of the particular assumptions made when comparing the commercial qualities of different classes of aircraft.

In conclusion he referred very briefly to M. Breguet's general conclusion that the higher cost of the faster aircraft should be more than met by the higher tariffs which it would justify and the increased traffic which would be derived from it. The question as to the extent to which the public was prepared to pay higher rates for faster air transport was one which could not be answered summarily. He thought he was correct in saying that air transport operators in general had not hitherto found the public very responsive to suggestions that they should pay higher rates for faster services. In this connection he could not do better than refer to the remarks of Sir Eric Geddes in his speech at the recent Annual General Meeting of Imperial Airways. He pointed out that if high speed services were required they could be provided, but someone had to pay. Either the public must pay higher rates or the Government concerned must make up the balance by higher subsidies.

Mr. H. O. Short (Fellow): His chief pleasure and interest in being present at the meeting was to have the honour of again meeting M. Breguet and of paying his respects to a great French pioneer of aviation. Knowing of some of M. Breguet's great activities, he was sure he was voicing the feelings of all present in saying that they were greatly indebted to him for sparing the time to come to this country to present the lecture.

Dr. N. A. V. Piercy (Fellow): The paper had been of tonic interest and he looked at it in a manner slightly different from that of previous speakers. Whereas they seemed to have discussed the question of the slow aeroplane *versus* the fast aeroplane, he personally had regarded the paper from the point of view of how far the fast commercial aeroplane was possible, supposing a demand for speed. From the scientific point of view Dr. Piercy would have liked to regard

speed limitation in aeronautics as coming in a roundabout manner from the velocity of sound. M. Breguet had said, firstly, that much more severe speed restrictions were imposed by present-day design; yet secondly, that the cost of increasing speed was negligible in aviation as compared with the corresponding costs in other forms of transport. Therefore, one concluded that increasing speed in aeronautics formed an attractive engineering study apart from the *strictly* commercial point of view.

There was no doubt that losses in cooling could be reduced in the near future. But further than that, could one expect any great improvement in the already highly developed large aircraft engine? That was for the engine experts to say. If not, they must consider reducing structural weight and minimum aerodynamic drag. Would the metallurgist say they could expect any great improvement in materials? Dr. Piercy doubted it. In that case, he suggested that unless revolutionary changes were brought about in aeroplanes—and M. Breguet had referred to several—they might perhaps consider again the suggestion, which was not new, of putting the heavy load farther out along the span and enclosing the load in the wing. But there again one met trouble, because very large aeroplanes were scarcely commercially possible at the moment, and on the other hand, Mr. Relf was not too optimistic as to what he could do in the matter of relatively very thick wings. However, Dr. Piercy asked M. Breguet if the twin fuselage layout, which had been studied for the last five years in France and Italy, was regarded in those countries as perhaps a preliminary step in that direction.

Finally, Dr. Piercy emphasised that aerodromes having really hard and smooth runways would become more and more urgently needed. Undercarriages of the kind with which they were all so familiar had done yeoman service in the past; but when they had to consider, from the point of view of attaining really high speeds, considerable alterations in the layout of an aeroplane, they might find that they had to dispense with that old and trusty type. In that case hard runways would probably become essential.

Mr. E. C. Gordon England (Fellow): There was a danger of the protagonists of the moderate-speed aeroplane and the high-speed aeroplane getting into considerable difficulty—and already some examples of that had arisen at the meeting. It seemed to him that, in order to make any true commercial comparison between either of these types, one must start with a fundamentally perfect ground organisation which gave each school of thought equal opportunity; he did not think one could get a proper comparison of the probable results that could be obtained either now or at some time in the future unless one started with a perfect ground organisation. It seemed that one could build up cases for either type, provided one was always prepared to miss out the factor of ground organisation, which he considered to be the governing feature. It was a purely practical point, but, like most practical points, it defeated all the theorists in the world when the problem arose of building up the balance sheets of operating companies. Whilst they were all very keen to provide the extra speed, and whilst those who were excusing their present performance, or justifying it, were being attacked by those who held that they should be doing something different, they merely got into a wrangle and put up arguments which were largely futile because this central factor of suitable ground organisation was missed. They should proceed very steadily in this matter of what constituted the most desirable and practical speed of operation and concentrate their attention on providing everywhere possible the finest ground organisation they could devise. Obviously, there were conditions in which they could use the higher speed, as explained by M. Breguet, but there were many cases also where that was almost an impossible proposition in view of the problem of lack of suitable ground organisation.

Group Captain G. B. Hynes (Air Ministry): From the power plant point of view, if they were to obtain economic higher speeds, a problem of outstanding

importance was that of fuel consumption. Reference had been made in the paper to consumptions of the order of 0.44lbs./h.p.; this was quite possible of attainment with present types of engines, but there were prospects, he believed, that they could do even better with the compression ignition engine. He had been very interested in the possibilities of that type of engine since he was at Farnborough, and it was, therefore, of particular interest to him to note that it seemed likely to be really coming to the fore. In a very short time they should have an opportunity, he believed, of getting a really good comparison.

One of the factors having a very important bearing was the problem of what exactly was the consumption actually realised under normal operating conditions. He had observed that M. Breguet, in his calculations, had adopted a figure of about 0.6lbs./h.p., which was rather comforting, because many assumptions are so often made on bench test figures which, he thought there was a great deal of evidence to show, were not realised normally in everyday flying. But with the compression ignition engine there was a much better chance of such figures being realised, for the fundamental reason that the power output of the engine is controlled by the amount of the fuel charge injected into it, and therefore it would not be left to the pilot, or to other devices, to attempt to fix the best and most economical mixture and then adjust the power by throttling the mixture at the carburettor. The compression ignition engine seemed to offer a valuable prospect in the direction of reducing fuel consumption, coupled with other advantages, such as the reduced risk of fire and freedom from interference with radio.

As one of M. Breguet's earliest pupils, and probably his oldest English pupil, Group Captain Hynes derived particular pleasure from meeting M. Breguet again. As a purely personal reminiscence, he would like to mention that he was flying M. Breguet's machines at La Brayelle, near Douai, in 1911.

Mr. O. E. Simmonds, M.P. (Member of Council): The paper was certainly very timely; and one point which M. Breguet's curves had indicated very clearly was that the last way in which one ought to increase speed was by increasing power. He fancied that in many statements made, and particularly in many of the pronouncements they had seen since the Melbourne race—which, of course, had made no difference to the policy of anybody, for the people concerned had all been determined many months ago to do what they are doing to-day—the facts seemed to be a jumble. Speed could be attained in a number of different ways, as M. Breguet had indicated—by split flaps, high wing loading, variable pitch propellers, and even by retractable undercarriages. Unless he was very much mistaken, one of their great, but very slow, air lines did not possess a single aircraft with a retractable undercarriage. If there was one way in which they could buy speed for nothing in aircraft, except the initial £50 or £100 outlay for the chassis and retracting mechanism, it was by using the retractable undercarriage.

Referring again to M. Breguet's most interesting curves, which he hoped would be studied carefully, Mr. Simmonds drew the attention of all who suffered from complacency or felt that they were on the defensive to the fact that as the speed decreased below a certain point the pay load was reduced because so much more fuel had to be carried. Unless he was very much mistaken, many British civil aircraft were not operating at the speed which gave the maximum useful load, but at a lesser speed, so that they were carrying too much fuel and their useful load was thereby reduced.

In view of the criticisms made of M. Breguet's conclusions as to the relative costs of the fast and slow machines, Mr. Simmonds suggested that in one respect, at any rate, M. Breguet had erred in favour of the slow machine, because, as he had mentioned in the paper, he had not allowed for any larger body for carrying the greater number of passengers. They all knew that when a larger number of passengers had to be carried, and a slow machine was required, a "hotel" was slung under the wing, and it had probably six or eight times the drag of a

really beautifully streamlined fuselage! There was also the point, to which M. Breguet had alluded, that in this country they were too apt to speak of "cruising speed" when they ought to refer to "normal speed of flight on the route." "Cruising speed" was essentially the speed in still air. As an example of his point, Mr. Simmonds referred to the experience of a Parliamentary colleague recently, who had flown to Paris on the evening machine. Because there was a 50 m.p.h. head wind the journey had occupied 3½ hours. If the average cruising speed of the machine had been 150 instead of 100 m.p.h., the journey would have occupied only half as much time, because the speed on the route would have been 100 m.p.h. instead of 50 m.p.h. In the development of civil air transport time was a very important factor. The country, and Parliament, were greatly interested in the question and were anxious for more speed on their air routes. Therefore, he appealed to all to think constructively and not to consider it so necessary to justify what they had or had not done in the past. If they looked at the matter frankly, bearing in mind what other nations were doing, they would do a great deal more good for the country and for civil aviation than they would by worrying about whose mistakes had caused the present state of conditions.

Squadron Leader S. N. Cole (*contributed*): With reference to the cost of maintaining aircraft in service, apart from normal daily inspection of aircraft and engines, all maintenance work, from the first overhaul inspection to completed service pipe, is based upon flying hours. The speed at which these flying hours are carried out is of very little account when maintenance instructions are being laid down. Thus, the difference in overhaul costs, and the man hours required to maintain those aircraft taken as examples by the lecturer may be considered as of negligible account.

Comparing aircraft of similar load capacity, for approximately the same maintenance costs, it is obvious that the pay load in ton/miles obtained from the life of the fast aircraft will be in excess of that given by the slower type. This fact should be taken into account and definite figures arrived at for the increase of points to the credit of the faster aircraft when commercial aircraft services are being organised.

Reply to Discussion

He reminded them that the progress which had been made in theory took some little time to put into practice. There was no doubt that aeroplanes would be developed capable of attaining 320 k.m.h. in two to three years' time, if from now onwards an effort be made to produce new materials.

In reply to Mr. Handley Page, he knew that the slow aeroplane which he had considered was in fact a fast machine for the period under consideration.

He would be able to take as a point of comparison a machine specially considered to be slow, that was to say one having a large surface relative to its weight. In that case the slow machine would only be effective actually at 160 k.p.h., for example, instead of at 240 k.p.h. which was desired.

The results of his investigations showed that such an aeroplane would be as costly to run as the aeroplane which he had considered.

In reply to the question put to him by Dr. Piercy regarding the future of twin-fuselaged aeroplanes, M. Breguet replied that this form was already popular by reason of the greater lightness of construction which was possible. But it seemed to him that this form was less effective from an aerodynamical point of view than that of a single fuselage. Two parallel fuselages had, in fact, a greater resistance than that of a single fuselage of the same maximum cross section, due to the aerodynamic interference between the two fuselages. For large aeroplanes of more than 50 tons the fuselages would be relatively weaker and better placed than for smaller aeroplanes, and that was a point in favour of a twin fuselage.

In reply to Group Captain Hynes' remarks, M. Breguet said he knew quite well that the consumption of 0.275 kg. which he considered, was a figure upon which improvement had already been made; but he considered that the figure that he had introduced in his calculations left a convenient margin to avoid being too optimistic.

He added that he knew that with compression ignition engines one could obtain a better consumption figure than 200 grams h.p. hour, but he estimated that there was already such progress in commercial aviation that one could, in practice, rely on 200 gr. per h.p. hour; that was why he did not wish to give a lower figure. He added that the net costs per ton/kilometre to which he had been led were figures which he did not believe were too optimistic. They were figures which, with the increasing development and competition among air transport companies, would certainly be reached in a few years. The cost of air transport to-day is high largely because of the accessory costs, that is, those costs other than those of the actual running of the aeroplanes. These costs are out of all proportion to the freight and passengers carried. He did not doubt that in the future the traffic would be quadrupled, if not increased tenfold, and then air transport will be less difficult to run than it is at present.

The PRESIDENT: Before proposing a vote of thanks to M. Breguet for his paper, and to Colonel O'Gorman for having translated the reply, he said he had been particularly interested in the discussion because he had wished to learn what would be the reply of the young idea in the Royal Aeronautical Society to the old " Pundits " who talked about paying for speed. They had heard of such remarks by Sir Eric Geddes, and from Mr. Handley Page, and he had expected some of the younger people to have suitably replied. But, to his astonishment, it had been left to a Member of Parliament to draw attention to the fact that it was not very economical to drag an undercarriage through the air, and Mr. Simmonds had also been the first to draw attention, in the discussion, to the use of split flaps and variable pitch airscrews. Then there was Wing Commander Hynes' reference to the compression ignition engine—and the President expressed the belief that nothing was more important for long-range high speed than the compression ignition engine, at a lower consumption. Again, he might be fussy, but he had a very great dislike of being burned alive—and there was no doubt that quite small accidents on an aerodrome sometimes turned into a bonfire. The success of civil aviation was very much wrapped up in safety, as was any other form of aviation.

In order to appreciate the paper fully it was necessary to study it carefully, for it contained much meat, which needed to be digested and taken advantage of in this country perhaps more than in any other.

M. Breguet seemed to provide ample proof that if one were a pioneer at any age one remained a pioneer and did not become an old fogey. In the early days he was talking of helicopters, and so on; now, 30 or 35 years later, he still retained the pioneer spirit and was able to put before them visions of higher speed and of a future for aviation which apparently had been forgotten by some of those who considered themselves expert in the subject. The members of the Society wished to join in thanking him for having given them a most entertaining lecture, and for his presence in person.

The vote of thanks was accorded and the meeting closed.

HIGH-SPEED AIRCRAFT DESIGN*

WITH SPECIAL REFERENCE TO THE D.H. "COMET"

BY

RICHARD M. CLARKSON, A.C.G.I., B.Sc., A.F.R.Ae.S.

(*Paper read before the Bristol Branch of the Royal Aeronautical Society on December 11th, 1934.*)

The MacRobertson Air Race, with its carefully thought out rules and conditions, has turned out to be one of the greatest incentives to the progress of aircraft design in the history of aviation. The fixing of the average distance between control points along the route of the race, together with the necessity for compliance with a British normal Certificate of Airworthiness, and the need for high speed all combined to make a problem for the aircraft designer the solution of which cannot but benefit very materially the advancement of aeroplane design.

Many long range records have been taken in the past, but never with an aircraft possessing a Certificate of Airworthiness. Many speed records have been taken, but few with an aeroplane which complies with Certificate of Airworthiness requirements. Here we had a contest which demanded of the aircraft the utmost range and speed consistent with the possession of a Certificate of Airworthiness.

In designing an aircraft for the race the maximum distance between control points (*i.e.*, compulsory stopping places) placed an upper limit of approximately 2,900 miles upon the necessary safe range (in actual fact, it was doubtful whether this range could be attained with a Certificate of Airworthiness on any aircraft). Furthermore, a minimum cruising speed of 200 m.p.h. was considered essential. The incorporation of a retractable undercarriage and some device for coarsening the glide and reducing the landing speed was a foregone conclusion. The desirability of using Gipsy Six engines on account of their good "power for drag" ratio was paramount.

The problem therefore resolved itself into determining the minimum power with which the above conditions could be met when carrying a crew of two with equipment; coupled with an investigation of the advisability of using V.P. propellers, supercharging, or any other possibly useful adjuncts.

A preliminary investigation established the necessity for using V.P. propellers and disclosed the existence of two alternative solutions to the problem when using two Gipsy Six engines:—

(*a*) High speed and moderate range (V.P. propeller possibly not absolutely essential).

(*b*) Moderate speed and sufficient range to eliminate the necessity for stopping between the control points. (V.P. propellers definitely essential.)

In the first case about 260 m.p.h. and 1,700 miles range appeared possible; and in the second case, a cruising speed of about 220 m.p.h. when carrying petrol

* All photographs used are by kind courtesy of *Flight*.

for 2,800 miles (the very minimum range necessary to make England-Baghdad—the longest control stage—in one hop).

After consideration of the geography and meteorology of the route, the probable time required for re-fuelling, the desirability of eliminating as many night landings as possible, and a variety of other details, it was decided that the second alternative—moderate speed and long range—was the better proposition and gave the machine a sporting chance of acquitting itself well in international contest.

V.P. Propellers

The higher the design speed of a F.P. propeller the lower will be its static thrust (and mean take-off thrust), *i.e.*, the faster the aircraft the more will the take-off suffer, due to bad propeller conditions at low speeds. The V.P. propeller enables this loss to be recaptured, *i.e.*, it improves the bad static propeller conditions of the fast aircraft until they are as good as or better than those of an average relatively slow machine. For a machine with a top speed of well over 200 m.p.h. the mean take-off thrust with V.P. propeller is about twice as much as with a F.P., which means that if the " Comet " were fitted with F.P. propellers its total weight would have to be considerably reduced in order that the take-off should still comply with Certificate of Airworthiness requirements. In actual fact it would be equivalent to a reduction of range from 2,800 miles to about 1,800. It will, therefore, be apparent that the V.P. propeller was a necessity in the " Comet." Furthermore, there is a practical point in connection with the engine which rendered the fitment of V.P. propellers in the " Comet " essential unless doped fuel was to be used, and this is that the static r.p.m. with fixed pitch propellers on an aircraft of 200 m.p.h. or more top speed are less than 75 per cent. of the maximum permissible r.p.m., and running at these r.p.m. at full throttle even for short periods is extremely detrimental to the engine owing to detonation.

A certain amount of *ad hoc* research work in connection with propellers for the " Comet " was done in a " Leopard " Moth with a Gipsy Six engine and consisted of take-off and climb tests with propellers of various pitches. Table I shows some of the results of these tests.

TABLE I.

PROPELLER TESTS ON " LEOPARD " MOTH WITH GIPSY SIX ENGINE.

1. Effect of High Design Speed on Take-off—Wooden Propellers.

All-up weight	2,400lbs.	2,000lbs.
Design speed, max. r.p.m. at	165 m.p.h.	240 m.p.h.
P/D ratio	0.9	1.56
Take-off run	197yds.	235yds.
Static r.p.m./max. r.p.m....	0.84	0.71

2. Effect of V.P. Propeller.

All-up weight 2,000lbs.

Pitch setting	Fine	Coarse
Max. r.p.m. at	70 m.p.h.	165 m.p.h.
Take-off run	190yds.	313yds.
Height attained at 600 metres from rest	250ft.	97ft.
Time to climb to 1,000ft. from rest ...	1 m. 02 secs.	1 m. 31 secs.
Static r.p.m./max. r.p.m....	0.94	0.82

3. Effect of V.P. Propeller—Another Test—Different Propeller.

All-up weight 2,400lbs.

	Fine	Coarse
Pitch setting		
Max. r.p.m. at	110 m.p.h.	165 m.p.h.
Height attained at 600 metres from rest	173ft.	87ft.
Time to climb to 1,000ft. from rest ...	1 m. 10 secs.	1 m. 23 secs.
Static r.p.m./max. r.p.m....	0.88	0.76

Range and Throttling

It was apparent that the required range could not be attained if the full b.h.p. of the engine were used.

There is, for any particular aircraft, a definite relation between the power which is used on the take-off and the load (or weight of petrol) which can be taken off the ground with a Certificate of Airworthiness (*i.e.*, with a given take-off performance). This petrol can be burnt at various rates corresponding to various power outputs (or fractions of the take-off power) when in the air,

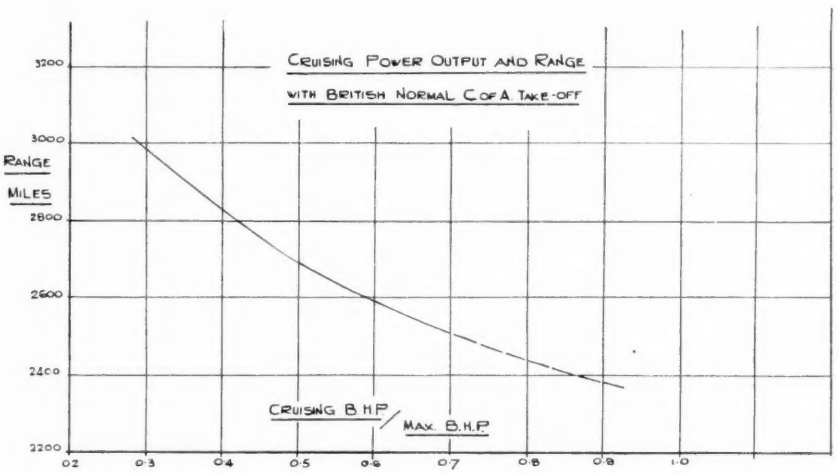


FIG. 1.

thereby giving various ranges and cruising speeds, the greater the power output the lower the range. There is, therefore, a definite relation between range and the ratio-cruising power output/max. power output (Fig. 1), which is found to be pretty much the same for aircraft of widely different maximum speeds provided they are all roughly equally clean. From Fig. 1 it is apparent that in order to attain a range of 2,800 miles at sea level the aircraft would have to be cruised with the engines throttled to 42 per cent. of their maximum output corresponding to a speed of about 72 per cent. of the maximum speed of the aircraft. By flying at a greater altitude, however, with the same power output, the aircraft will travel faster on account of the lower atmospheric density, and therefore attain a greater range; or, conversely, the throttle may be further opened until the range is reduced to the original figure, which will then be accomplished at a considerably higher forward speed than at sea level (Fig. 2). The variation of specific fuel consumption with power output (whose effect is contained in the

curves) further favours the benefit of flying high. From Fig. 2 it will be seen that, at 10,000ft. for instance, 2,800 miles range may be attained with the engines developing as much as 66 per cent. of their maximum output, corresponding to a speed of about 94 per cent. of the maximum sea level speed of the aircraft. Hence the importance of flying high for the race, where range and speed are both simultaneously important. The higher one flies the greater is the cruising speed which can be used whilst conforming to the range and take-off requirements (Fig. 3). Ultimately, an altitude is reached where the cruising power taken out of the engine becomes equal to the maximum engine power obtainable at that altitude; in other words, the cruising speed for 2,800 miles range equals the maximum speed of the aircraft at full throttle, and represents the greatest speed at which the required range can be attained. Below this altitude the engine must be throttled as we have seen to a lower cruising speed, whilst above this altitude the full throttle maximum speed falls off, and the range becomes greater than required.

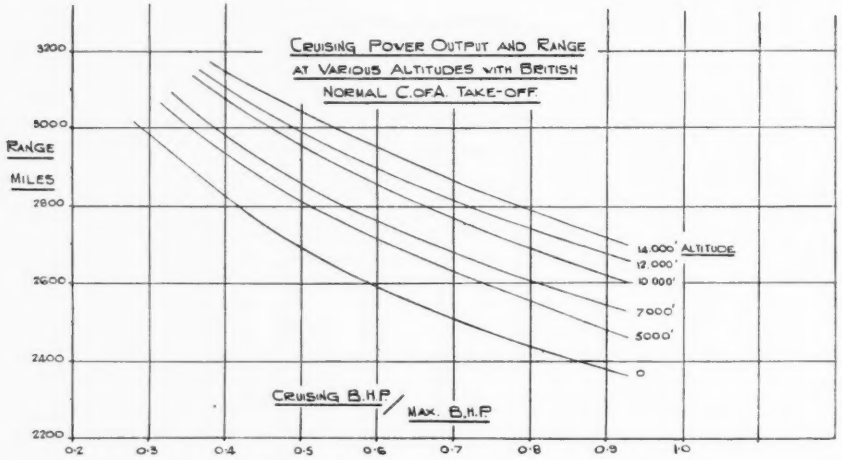


FIG. 2.

It will be seen from Fig. 3 that this optimum altitude is in the neighbourhood of 10,000ft. where 2,800 miles range is attained at a speed of approximately 223 m.p.h. for a power output of approximately 66 per cent. maximum. These, then, were the most efficient operating conditions for the " Comet " in the race, and it should be noted that although the throttles were fully open, the power output was no more than at normal cruising conditions at sea level; and the r.p.m. could be held down to the desired cruising figure with a V.P. propeller.

The undesirability of asking the pilots to fly throughout at this altitude was fully appreciated, but the alternative of throttling at lower altitudes on curve A in Fig. 3 resulted in too large a sacrifice of speed.

Supercharging

Whilst the value of V.P. propellers in the MacRobertson race is fairly apparent, there has been a certain amount of misconception as to the effect of supercharging where speed and range are simultaneously desired. It was desirable to retain the simplicity and light weight of the normally aspirated engine unless supercharging appeared to be a material benefit.

Supercharging at low altitudes is of no value since the engines already have to be heavily throttled in order to attain the range.

Supercharging at 10,000*ft.* gives increased speed with increased petrol consumption and therefore requires more fuel to maintain the range. It follows that more power must be available on the take-off in order to lift the extra weight of fuel over the screen, thus requiring a much greater power output on the take-off than would be allowed by the existing Civil Airworthiness regulations in this country.

Supercharging at altitudes above 10,000*ft.* allows us to work on the dotted continuation of curve A, giving the increase of speed shown for the same range and without the necessity for using increased power on the take-off. Had it

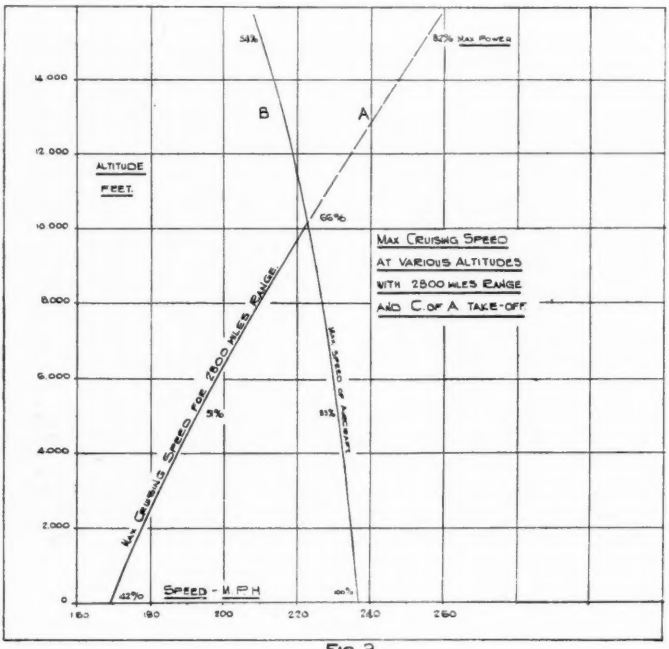


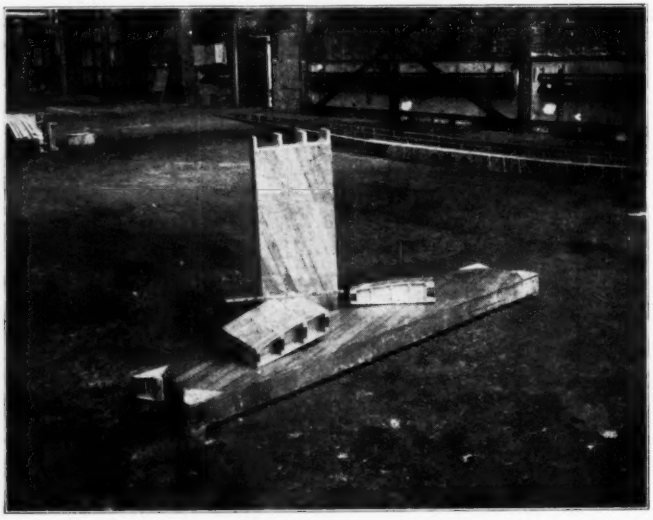
FIG. 3.

seemed impossible to obtain the desired range with supercharging, we could have got it by supercharging and working in the area above 10,000ft. bounded by curves A and B.

It, therefore, appears that supercharging can only be usefully employed at the expense of imposing upon the pilots the discomfort of flying at altitudes considerably in excess of 10,000ft. There is also the added weight of supercharger, clothing, and equipment, and the reduction of take-off h.p. due to the presence of the supercharger which can only be overcome by " ground boosting," requiring either the use of doped fuel or a lowering of the compression ratio, all of which tend to offset the increase in performance shown on the dotted curve of Fig. 3. In view of this and the fact that it seemed just possible to attain the required range and speed with normally aspirated engines, supercharging was abandoned.

Engines

It was decided to use standard Gipsy Six engines with the compression ratio increased from 5.25 to 6.50, for reasons of economy and power, and to run at " weakest maintained " at full throttle at 10,000ft. on DTD. 224 spirit (experiments were made with a lighter petrol but trouble was experienced with detonation). This corresponds to 78 per cent. of the power output at which the type test was run. It was further decided to run on cold air from a forward facing intake, with no heat to the induction system; but provision was made for switching over to hot air in the event of freezing in the carburettors being encountered. The increased power obtained by running on the forward facing intake instead of on hot air restricted by the flame trap amounted to about 15 per cent., corresponding to 12 m.p.h. of speed, and this coupled with the absence of any distribution troubles justified the adoption of this procedure.



½-scale test spars.
Showing 4-web and 2-web specimens with failure.
Spars and slats in background.

A specific consumption under the above conditions of 0.5 pints/b.h.p. hr. was obtained, corresponding to 20 gallons/hr. for the aircraft.

The engines were arranged to run at 0.60 pints/b.h.p. hr. at full throttle near the ground for take-off and climb, and sufficient mixture control was provided (37 per cent.) to obtain " weakest maintained " at all altitudes up to 14,000ft. in the event of it being impossible to fly all the time at 10,000ft. It will be appreciated that flight at altitudes above 10,000ft. gives increased range at the expense of speed, and that flight under these conditions with heated induction system gives still greater increase in range in exchange for speed, and pilots were instructed to use this method of increasing their range should occasion demand it.

It was very important to guard against pilots running at " weakest maintained " at large power outputs (corresponding to full throttle at low altitudes) with consequent damage to the engines. For this purpose a negative boost

gauge was connected to the induction manifold, and weakening was only permitted when the boost was less than −3lbs. per sq. inch, corresponding to full throttle at altitudes above 7,000ft. This meant that, if for any purpose it was necessary to fly below 7,000ft., the engines must be throttled to −3lbs. per sq. inch boost (about 75 per cent. maximum power) before mixture control could be used, alternatively, the engines could be run at full throttle below this altitude, but only on rich mixture with corresponding greatly reduced range.

Table II shows the engine r.p.m. and approximate power output under various conditions of flight.

TABLE II.

D.H. "COMET."

ENGINE R.P.M. AND POWER OUTPUT UNDER VARIOUS CONDITIONS (COLD INTAKES).

Condition.	Pitch Setting.	R.P.M.	Approx. B.H.P
Test bed—			
Max. permissible r.p.m.—full throttle	—	2400	95% max.*
Type test (normal r.p.m.—endurance test power)	—	2350	86% ,, *
Speed—			
Cruising at 10,000ft.—full throttle ...	Coarse	2250	67% ,,
Cruising at 7,000ft. at −3lbs. sq. in. boost	,,	2290	72% ,,
Cruising at sea level at −3lbs. sq. in., boost throttled	,,	2000	60% ,,
Full throttle at sea level	,,	2370	100% ,,
Climb, etc.—			
Full throttle static	Fine	2150	87% ,,
Full throttle climb, 100 A.S.I. at sea level	,,	2400	96% ,,
Full throttle climb, 150 A.S.I. at 2,000ft.	Coarse	1950	76% ,,

* Without dynamic pressure on the intake due to forward speed.

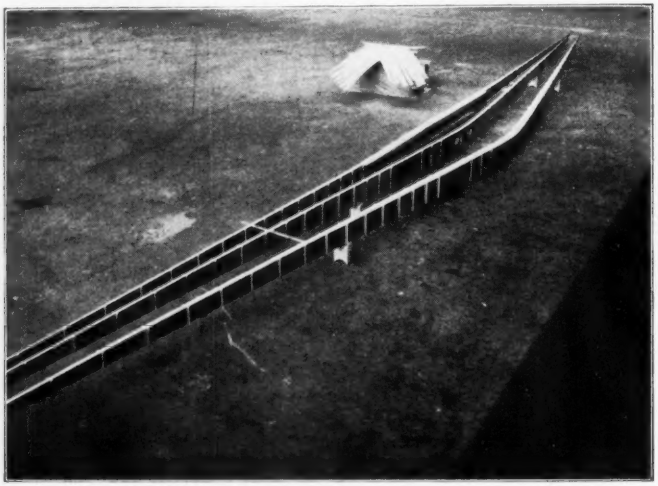
The Aircraft

The most interesting feature of the aircraft from the constructional point of view is the wing and spar structure. With a twin-engined layout it was found difficult to get the necessary torsional stiffness with a wire-braced structure without incurring excessive interference and parasite drag. A pure cantilever structure was therefore decided upon, and in order to keep the spar depth and weight as low as possible it was decided to go for a stressed skin structure—our first experiment in this field.

An extensive programme of strength tests was carried out in order to develop a satisfactory type of construction and to determine what stress could be developed in the skin. For this purpose a series of half-scale models of the spar of constant section and 8ft. span were made up and tested in pure bending under a single central load. The type of spar evolved is shown on page 220.

Approximately the middle half of the chord is occupied by a single spar continuous across the fuselage and consisting of a spruce skin separated and stiffened by three-ply wood subsidiary spars which function as shear members running from tip to tip, and also supported in a fore and aft direction by ply rib diaphragms. The spruce skin is built up of diagonal laminations, 2in. wide and $\frac{1}{8}$-$\frac{1}{4}$in. thick, to any desired total thickness, the maximum thickness at the root is about $\frac{5}{8}$in. reducing to $\frac{1}{2}$in. at the engines and $\frac{1}{4}$in. near the tip. It was possible to work to an ultimate bending stress of 4,000lbs. per sq. inch with

this type of construction, and a remarkably thin, though stiff, wing was possible. The maximum depth of the wing section at the root was no more than 11½ inches. This construction also proved reasonably light, the total wing structure including split flaps, ailerons, with internal mass balances, covering, and all fittings and fairings, but excluding engine mountings, weighed 2.92lbs. per sq. foot or 11.2 per cent. of the all-up weight of the aircraft (5,550lbs.) and was designed to a C.P. forward factor of safety of 6.2. The heavy loading on the structure (26.1lbs. per sq. ft.) is partly responsible for the low percentage structure weight.



Spar webs without stressed skin,
Spaced approximately as in wing.
Showing sweepback, rear spar stiffening,
slats for skin in background.

The split trailing flaps with a maximum travel of 37° extending over the middle one-fifth of the span, and occupying the rear one-fifth of the chord, proved very effective indeed in coarsening the glide and reducing the stalling speed;

Split flaps fully open.

they also performed the function of a tail trim in causing the machine to trim tail heavy when pulled down after throttling the engines before gliding in. There was no time to obtain any accurate measurements, but they appeared to reduce the stalling speed by about 10 m.p.h., equivalent to approximately a 30 per cent. increase in effective maximum K_1. Half flap angle was found very beneficial on the take-off.

The wing section was a modified R.A.F. 34 section, being similar to the " Leopard " Moth with the leading and trailing edges raised slightly; it had a fairly stable C.P. travel (moment coefficient at no lift $= -0.0067$). The maximum C./L. camber and maximum thickness were 1.75 and 12.2 per cent. respectively. This section was maintained throughout except near the root where the rear spar depth was slightly increased.

General

Most of the interesting detail design features have been described and illustrated in the technical press and call for no further comment. The relative disposition of crew and fuel was dictated by considerations of C.G. travel, otherwise it would have been preferable to have the crew in the nose; 238 gallons of petrol were located approximately on the C.G., the remaining 20 gallons being aft of the crew for trimming purposes. The extreme nose was occupied by the accumulator, emergency rations and drinking water, and landing light. The engines were slung under the wings thereby leaving the airflow over the upper surface as unrestricted as possible, avoiding interference with the fuselage, and providing space in which to conceal the undercarriage when retracted. The tailplane was fixed and built into the fuselage, trimming being accomplished by spring-loaded elevators. The undercarriage is retracted by means of cables operating telescopic screws. All control surfaces were provided with a differential motion to maintain lightness at high speed, and very little trouble was experienced in getting them right in flight.

The utmost attention was paid to detail cleanness, and all excrescences and protuberances were reduced to the very minimum. Petrol filler caps were fitted with covers flush with the fuselage surface, the forward facing intakes were fitted in the nose cowl, the aileron mass balance was concealed within the wing, and there were no bolts, nuts or rivets protruding on any part of the structure. The venturi for working the navigation instruments was eliminated by running the instruments off an engine-driven suction pump, and carrying an emergency venturi in the cockpit which could be clamped on the fuselage side by the pilot whilst in flight.

The aircraft was fitted with all the normal instruments, including the following navigation instruments:—

2 Sperry artificial horizons.
2 Sperry directional gyros.
2 Air speed indicators.
2 Compasses (P.4).
Smith's electrical fuel gauges.
1 8-day clock.

All controls were dual except the undercarriage retracting gear, flap operating lever, petrol cocks, flame trap levers, and landing light control, which

were operated from the front seat only, from which the aircraft was always landed and taken off.

Wireless was not included.

Showing propeller discs, Ratier blades, forward facing intakes, flaps down.

The propellers were of the Ratier pneumatic V.P. type, in which an air pressure of 80lbs. per sq. inch in an air reservoir maintains the propeller blades in the fine pitch setting for take-off and climb. When a certain forward speed (about 150 A.S.I.) is attained the dynamic air pressure on a forward facing disc on the spinner nose releases a valve, thereby deflating the air reservoir and allowing the centrifugal force on the blades to rotate them into the coarse pitch setting. This is effected by securing the blades to the boss by mounting them on a spiral ball race which causes them to rotate into coarse pitch under the action of centrifugal force. The centrifugal twisting moment on the blades opposes the above twisting effect, thereby reducing the net forces to reasonable proportions for operation. In order to return the blades to fine pitch the aircraft must be landed and the air reservoir re-inflated with a bicycle pump. The reason for using this propeller instead of the Hamilton was that the blade shape and sections of the Ratier were designed for an air-cooled in-line engine of the Gipsy type and gave higher top speed and better engine cooling at low speed than the Hamilton, which was a modified radial engine propeller. In the limited time available it would not have been possible to develop a suitable Hamilton propeller.

D.H. " COMET "—GENERAL DATA.

Weights, Etc.

Tare weight (including 20lbs. removable equipment) ...	3,003 lbs.
Petrol—258 gallons at 7.6lbs./gallon	1,962 ,,
Oil—16 gallons at 9.7lbs./gallon	155 ,,
Emergency drinking water—3 gallons	30 ,,
Crew and equipment	400 ,,
Maximum permissible weight	5,550 ,,
Weight with almost empty tanks	3,600 ,,

Total wing surface, 212.5 sq. ft.
Overall span, 44.0ft.
Maximum b.h.p., 470.

Wing loading, 26.1lbs./sq. ft.
Span loading, 2.87lbs./ft.^{2}.
Power loading, 11.8lbs./h.p.

BRITISH NORMAL FACTORS OF SAFETY.

C.P. forward (0.25 chord) ...	6.22	
C.P. aft (0.35 chord)	4.70	C.P. limits on aerodynamic mean chord, 0.28-0.35.
Landing	4.50	
Up gust, down gust, fast glide ...	2.0	

APPROXIMATE ESTIMATED PERFORMANCE ON FULL LOAD BASED ON TEST RESULTS.

Maximum speed at sea level, 235 m.p.h.
Initial rate of climb, coarse pitch, 900ft./min.; fine pitch, 1,200ft./min.
Time to climb to 10,000ft., coarse pitch, 20 mins.; fine pitch, 13 mins.
Absolute ceiling, coarse pitch, 19,000ft.
Take-off run, 420yds.
Height attained at 656yds. from rest, 70ft.
Landing run, 270yds.
Stalling speed (with flaps), 78 m.p.h. (63 m.p.h. light load) } K_L max.
Absolute ceiling on one engine, full load, coarse pitch, 3,000ft. } 0.84.

Performance

Very little time was available for accurate performance measurement, but the speed at 10,000ft. appeared to be approximately 225 m.p.h. on a medium weight, about 5 m.p.h. in excess of the estimate; whilst the petrol consumption was slightly less than 20 gallons/hr. The corresponding ultimate range with full tanks was 2,900 miles, about 100 miles in excess of the estimate. At the same time the "Comet" complied comfortably with the Airworthiness requirements for take-off, climb and landing.

The ranges and times obtained by the competitors in the race, particularly on the Mildenhall-Baghdad section, when considered in conjunction with the

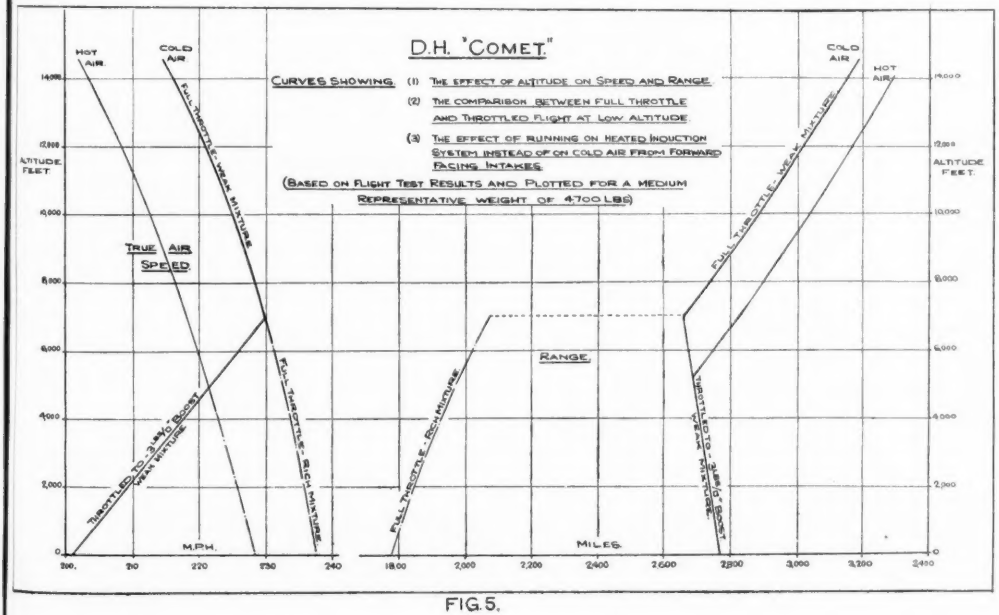


FIG. 5.

known petrol consumption, seem to confirm that the above-mentioned speed cannot be far in error.

We frequently analyse the performances of our aircraft by Professor Melvill Jones' method described in his paper " The Streamline Aeroplane." This method attempts to account for as much as possible of the b.h.p. developed by the engine at top speed, in the shape of propeller loss, induced drag, and skin friction drag on the total wetted surface of the aircraft (called " streamline drag "), leaving a balance of drag which is not accounted for and is due to eddies, interference, and form drag. The maximum speed attainable if this interference and eddy loss were absent is then calculated (called the " streamline speed ") and the ratios —total friction drag/streamline drag and—actual speed/streamline speed are used as figures of merit expressing the cleanness of the aircraft. The following is the analysis for the " Comet " on the medium weight of 4,700lbs. :—

D.H. " COMET "—PERFORMANCE ANALYSIS BY " JONES " METHOD.

Weight, 4,700lbs. Max. speed at sea level, 236 m.p.h.
B.H.P., with forward facing intakes, 470.

	h.p.	%
Loss in propeller (84 per cent. η)	75	16
Induced drag	20	4
Skin friction on wetted surface (streamline drag) ...	254	54
Balance = interference, eddies, etc.	121	26
Total—b.h.p.	470	100%

Total friction drag/streamline drag = (254 + 121)/254 = 1.48.
Streamline speed = 269 m.p.h.
Actual speed/streamline speed = 236/269 = 87.7 per cent.

COMPARISON WITH OTHER AIRCRAFT.

	Total Friction Drag / Streamline Drag.	Actual Speed / Streamline Speed
	%	%
*" Comet "	1.48	87.7
*" Douglas " D.C.2	1.77	82.6
Racing " Tiger " Moth monoplane (1927) ...	2.17	77.2
" Leopard " Moth	2.18	77.1
" Swallow " Moth (cantilever monoplane) ...	2.42	74.5
" D.H.86," four-engine air liner	2.43	74.4
" Moth "	3.84	63.8
" Hercules "	4.47	60.7

* Retractable undercarriages.

It appears from the above that the " Comet " is only 33 m.p.h. slower than it would be if perfectly streamlined and free from interference. In fact skin friction accounts for fully two-thirds of the total resistance. It is doubtful if this figure has ever before been attained in anything except racing seaplanes.

Comparisons, by the " Jones " method, between the " Comet " and several other aircraft are shown in the table. The improvement in aerodynamic cleanness during the last ten years or so may be seen by comparing the following pairs of machines:—

The " Hercules " (1925) and the " D.H.86 " (1934); the " Moth " (1925) and the " Leopard " Moth (1933); the Racing " Tiger " Moth monoplane (1927) and the " Leopard " Moth (1933).

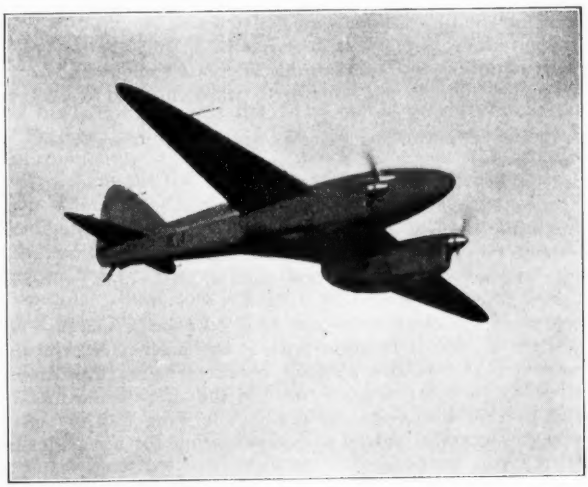
The " Douglas D.C.2 " is also interesting.

It is always necessary when making comparisons to bear in mind the peculiar limitations of any particular cut and dried method of comparison.

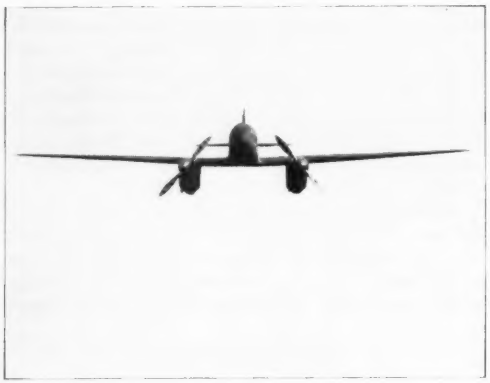
The foregoing facts and figures, I think, demonstrate that the " Comet " was a long range aircraft with high cruising speed and not a freak racing aeroplane as many people have supposed it to be. The fact that all three " Comets " have been landed and taken off on both light and heavy loads, in daytime and night, on all kinds and sizes of aerodromes and in some cases not on aerodromes at all, and under conditions of tropical heat, without a single mishap, has amply demonstrated its robustness and handling qualities and dispelled any doubts that existed as to the advisability of working to a wing loading of 26lbs. per sq. ft.

I have dealt at some length with the problem of the attainment of the range and speed with Certificate of Airworthiness, as this was, I think, the most vital and at the same time the most interesting of all the problems involved in the design of the " Comet."

" Comet."



Showing undercarriage retracted, cooling air outlets and inlets for oil tank cooling.



Showing thin wing roots (also Hamilton propellers).

General Considerations

The cruising speeds of commercial aircraft have gone up fairly rapidly from about 140 m.p.h. to over 200. This increase of speed has brought with it a number of constructional problems and modifications, of which the following are a few:—Fabric covering on any exposed part of the structure is impracticable on account of the heavy loading it is liable to sustain, and its increased tendency to pant; for a similar reason our ideas on the necessary stiffness of cowling have had to be considerably modified. Increased vigilance in safeguarding against flutter has been essential, involving careful mass balancing of all control surfaces, the determination of the positions of the flexural and inertia axes of the wing and an endeavour to locate them as near as possible to the axis of independence, and the necessity for keeping the flexural and torsional stiffness of the wing as high as possible.

Cantilever wings and tail surfaces have become general in the interest of cleanness, and the need for keeping them as thin and light as possible has necessitated the development of stressed skin construction.

The significant thing about this 50 odd m.p.h. increase in cruising speed is that it has been attained for a negligible increase in power (*i.e.*, it has been purchased cheaply). This is due chiefly to the combined use of the following devices:—

The utmost attention to general and detail aerodynamic cleanness of design.
Wing flaps.
The retractable undercarriage.
The variable pitch propeller.
The supercharger.

An attempt will be made to show how each of these devices has influenced the problem, and how interdependent they all are.

In the first place the clean aeroplane enabled a large increase of speed to be attained at small cost, but it brought with it the problem of the flat glide with which are associated undesirable landing characteristics, thus necessitating the fitting of some device for increasing the drag of the aircraft and thereby coarsening the glide; hence the air brake and ultimately the wing flap or split trailing flap which proved very successful indeed in compensating for the undesirable qualities associated with a clean aeroplane.

The wing flap, however, performs another important function: by materially increasing the maximum lift coefficient it permits of a considerable increase in

the wing loading, with consequent reduction of wing area and the size of all items dependent thereon (tail area, fuselage length, etc., etc.), *i.e.*, it permits of the building of a smaller and therefore faster and lighter aeroplane. The undercarriage then becomes a larger proportion of the total aircraft drag and is therefore worth retracting. (It is doubtful if the retractable undercarriage is worth while below speeds of 160 or 170 m.p.h.) The reduction of wing area with flaps, together with the need for as much span as possible for take-off, leads to the tapered plan form which is again economical in structure weight.

The high speed attained by the above devices introduces bad propeller conditions at the other end of the speed range involving serious reduction in thrust which would necessitate a large reduction in all-up weight in order to get safely off the ground, if it were not for the V.P. propeller which restores the good static propeller conditions which had been lost by pitching the propeller for high speed.

It will be seen that the V.P. propeller used in this way does not increase cruising speed, it merely renders high speed commercially usable. It has, however, another use which does materially increase the cruising speed. Maximum safe cruising speed is generally determined by some safe limit to the engine r.p.m. for continuous operation; these r.p.m. are known as "normal r.p.m." and are usually about 87 per cent. of the maximum permissible r.p.m., and correspond with F.P. propeller to only about two-thirds the maximum power output of the engine. This power output cannot be raised to the perfectly reasonable figure of, say, three-quarter maximum, or utilised at an altitude where the atmospheric density is lower and the cruising speed of the aircraft therefore higher, because the safe r.p.m. limitation would be exceeded. With the V.P. propeller, however, the r.p.m. can be held down to normal whilst the throttle is opened to say three-quarters maximum power output. Furthermore, this may be done at some altitude (approximately 5,000ft.) where the full throttle power of the engine at normal r.p.m. has automatically fallen off to three-quarters maximum at sea level, thereby further increasing the cruising speed of the aircraft. In this way, therefore, the V.P. propeller is used to increase the cruising speed.

Finally, we come to the supercharger, full advantage of which cannot be taken without the use of the V.P. propeller. The supercharger still further increases the cruising speed by enabling the safe cruising power output of the engine to be developed at some considerable altitude where the reduced atmospheric density permits the aircraft to travel still faster.

Table III represents an attempt to show in a more quantitative way the relative effects of the above-mentioned inter-dependent devices on cruising speed. It relates to aeroplanes having the same total weight, maximum power, and take-off and landing performance. The basic aeroplane (No. 1) has a cruising speed of approximately 150 m.p.h., which is about the greatest practicable cruising speed without the use of the interdependent devices. Nos. 2 and 3 represent transition stages, and are not very practical aeroplanes; No. 2 would have an impracticably flat glide and poor take-off, and No. 3 would not be able to take-off safely with full load. In No. 4, however, the take-off and landing characteristics of the basic aeroplane have been restored, and the cruising speed raised by 38 m.p.h. First cost will be a bit higher, maintenance charges a little more, and pay load about 10½ per cent. less; on the other hand, all the "per hour" costs (maintenance, fuel, oil, piloting, etc.) will be relatively less on a per mile basis because of the higher cruising speed. The result of this is that the total operating expenses of aircraft No. 4 on a cost per passenger mile basis are little or no greater than on aircraft No. 1, in spite of the large increase in cruising speed.

Nos. 5 and 6 illustrate further increase in cruising speed resulting from the addition of a supercharger. There is an increase in M.P.G. and a reduction of pay load, total operating cost is slightly lower.

TABLE III.

EFFECT OF VARIOUS DEVICES ON CRUISING SPEED.

CONSTANT TOTAL WEIGHT, MAXIMUM POWER, TAKE-OFF AND LANDING PERFORMANCE.

	Aircraft.	Max. Speed at Sea Level. m.p.h.	Cruising Speed. m.p.h.	Cruising Condition.	Relative m.p.g.	Relative Pay Load.
1	Basic aeroplane	173	147	Sea level, two-thirds max. power	1.0	1.0
2	Clean monoplane—					
	Retractable undercarriage ...	189	161	,, ,, ,,	—	—
3	With flaps—reduced size ...	200	171	,, ,, ,,	—	—
4	With flaps and V.P. propeller	198	185	5,000ft., three-quarters max. power	1,12	0.90
5	With flaps, V.P. propeller and supercharger	193	190	8,000ft., ,, ,,	1.15	0.84
6	With flaps, V.P. propeller and supercharger	193	201	14,000ft., ,, ,,	1.21	0.87

HOW TO OBTAIN AN AERO PATENT

BY

AN HONORARY FELLOW

In the early days of aviation in 1910 when Rolls, Egerton, Ogilvie and Grace were flying the open machines at the Aero Club's flying ground at Eastchurch, Grace made the interesting statement that in a few years aircraft design would develop under a continuous flow of invention in the same way as the motor car was then developing. Had Grace lived he would have been astonished at the truth of his prophecy, for the subject known at the Patent Office under the head of " Aeronautics " has developed into one of the greatest industries in the world, and by the end of the year 1930 the abridgments on Aeronautics had become one of the stoutest volumes in the patent classification. In spite of this growth which marked out the subject for a department of its own, for some inscrutable reason the Patent Office then decided to mix up aircraft with ships and thenceforth have published these two subjects in a single group instead of keeping them separate as before that time.

There are now over two hundred patents granted on the subject of aviation every year and the number is increasing so quickly that the Secretary of the Royal Aeronautical Society has recognised that out of the fifteen hundred members a large majority on the technical side must at some time or other come in contact with aeronautical inventions and with the patents which control the use of those inventions. Many of the senior technical members have acquired considerable experience in obtaining patents, but it is for those who are less familiar with the subject that this article has been compiled as a first aid in the somewhat complicated procedure of protecting one's ideas.

1. Essentials of Patentability

When the invention has been made the inventor who has had long experience in such matters goes to his patent agent to whom he describes the invention, pointing out its advantages. The conduct of patent agents is governed by a body, the Chartered Institute of Patent Agents, from whom can be obtained a list of the persons qualified to practice as patent agents.

When advising the inventor on the question of whether or not to take out a patent, the patent agent has to consider two things, firstly, whether the invention itself is a patentable one; and, secondly, whether, assuming it is something that can be patented, it possesses sufficient novelty and ingenuity to justify the filing of a patent application.

As to the first point, the agent is guided by the consideration that patents are granted for new manners of manufacture. Thus a mere scheme, such as a new system of controlling an air race, cannot be patented however ingenious it may be, and the only protection that can be obtained for such a scheme is that afforded by copyright (*e.g.*, copyright in a set of instructions) or that afforded indirectly by the registration of a trade mark which is, of course, only suitable in special cases. Assuming, however, that the invention submitted relates to a manufacture such, for instance, as a new form of wing structure, a method of controlling the fuel supply of an aircraft to suit the altitude at which the aircraft is flying, etc., the invention will be a patentable one if it is novel.

The Patent Office examiners make a search to test the novelty of the invention for which the patent application is made and report as to whether or not the invention is anticipated by prior specifications, and a substantial part of the patent agent's work in addition to drafting the specifications and claims, is amending patent applications to meet these objections. The province of the Patent Office examiner in England does not, however, go beyond deciding whether or not the invention is a novel one. This is very different from the practice in many foreign countries. Thus in Germany and in the U.S.A. it is open to the examiner to reject a claim on the ground that the invention covered by it, although novel, does not constitute an advance in the art of sufficient magnitude or ingenuity to justify the grant of a patent. Again, in France and Italy no examination as to novelty is made at all. In Great Britain it is the duty of the Patent Office to grant a patent provided there is some feature of novelty in the invention, however insignificant. To enforce his rights under a patent however, should anyone infringe his claims, a patentee must go to the High Court, and in an action for infringement the Court can consider many grounds for invalidating the patent which are not open to the Patent Office examiner. Such grounds include the objections that the invention does not involve sufficient ingenuity to support a patent, that it is not useful, that the directions given in the specification are not sufficient to enable the invention to be carried into practice, and that the patentee has not disclosed in his specification the best method known to him of carrying the invention into practice. These questions are of such a complicated nature that it requires the machinery of a Court of Justice to decide them, and it is for this reason that the investigation conducted by the British Patent Office, which does not have the facilities of a Court of Justice, is limited to questions of novelty and clear description of the invention. Not one per cent. of the patents issued are ever litigated, because if the invention is a good one and the specification and claims are skilfully drawn, rivals who might otherwise like to infringe frequently prefer to take a licence rather than dispute the patentee's just rights.

2. *Taking Out the Patent*

Returning to the patent agent, if he decides from his conversation with an inventor that the invention is one which is inherently patentable and that, so far as he is aware, it is free from anticipation, he will advise his client to seek patent protection by filing a provisional specification. The provisional specification is accompanied by an application form signed by the inventor, and when filed at the Patent Office secures provisional protection for the application. The invention is now protected for a period of twelve months and any time within that provisional protection period the complete specification with drawings may be prepared and filed.

Alternatively, the applicant may file a complete specification in the first instance, but a provisional specification is usually preferable, as allowing scope for introducing future developments in the invention. When the complete specification has been filed, the Patent Office make the official search amongst earlier patents and in the course of two or three months the Comptroller of Patents writes to the inventor, or his agent, quoting the numbers of any earlier patents which the examiner considers to anticipate, wholly or in part, the invention as claimed and calling for amendment of the description if he considers that the invention is not sufficiently clearly defined. The patent agent then revises the specification, as may be necessary, and submits the amendment to the inventor, pointing out how it is desirable to modify the claims in view of the earlier state of the art. This earlier art does not necessarily mean that some earlier patentee holds a patent which will prevent the inventor constructing his invention or selling it; it generally means that it lessens the extent of the monopoly which the inventor originally hoped he would obtain. However, the claims, even when limited in

view of the state of the art disclosed by the Patent Office search, may still be broad enough to cover a very useful field. After the specification has been amended to the satisfaction of the Comptroller the specification is accepted and is then printed and published by the Patent Office at the price of one shilling. The application remains open to opposition for a period of two months, during which time anyone who can show an interest in the invention may oppose the grant of the patent with a view either to having the patent refused or having some modification inserted in the specification. If no opposition is filed, as is the case in over 90 per cent. of the complete applications, the patent is granted on the payment of the sealing fee.

3. *Costs of Taking Out a Patent*

As a typical example of the costs of filing a patent application through a chartered patent agent the following may be quoted:—

Preparation and filing of the provisional specification £4 10s. 0d. (including £1 0s. 0d. Government stamp).

Preparation and filing of the complete specification and drawings £15 0s. 0d. to £21 0s. 0d., according to length and complexity (including £4 0s. 0d. Government stamp).

Amendment of the specification to meet citations revealed by the official search £5 0s. 0d. to £6 0s. 0d.

Payment of the sealing fee £2 5s. 0d. (including £1 0s. 0d. Government stamp).

Once the patent has been sealed it remains in force for a period of four years from the date of application without further payment. At the end of this period annual taxes become payable, commencing at £5 0s. 0d. for the first year, and increasing by £1 0s. 0d. each year until the final tax of £16 0s. 0d., in respect to the sixteenth and last year, is reached. These taxes may be reduced by 50 per cent. if the patentee has his patent endorsed "Licences of Right," which gives the Comptroller power to grant licences on reasonable terms should the patentee himself fail to act reasonably in this respect.

One of the objects of granting patents is to secure the working of inventions in the United Kingdom, and if a patentee either does not work the invention at all or else supplies the demand in this country solely by importation, and refuses to grant licences to others on reasonable terms, interested parties may apply to the Comptroller for the grant of a compulsory licence. Before taking the drastic step of granting such a licence the Comptroller will consider any special circumstances, such as difficulty in arranging for manufacture in this country, which may have prevented the patentee from working his patent here.

The British patent covers Great Britain, Northern Ireland and the Isle of Man. Separate patents are required to protect the invention in each of the Dominions and in each foreign country. Roughly speaking, the cost of filing a patent application abroad can be reckoned as about £30 per country; and in countries such as Germany and the U.S.A., where the examination by the Patent Office is severe, at least £10 should be set aside to meet possible objections by the Patent Office.

The inventor who desires to protect an aeronautical invention abroad can have all the work done by his patent agent in England. The countries chosen will, of course, vary with the importance of the invention and the money which the inventor is prepared to spend, but the countries of most importance from the aeronautical view-point are U.S.A., Germany, France, Holland and Canada, although the list can, of course, easily be extended.

Annual taxes need to be paid in nearly every country to keep the patents in force, and the term of the patent varies from 15 to 20 years according to the country. In U.S.A. the patent remains in force for 17 years from the date of issue of the patent without payment of any taxes at all.

4. *The Inventor and the Manufacturer*

An inventor should always file a provisional application before submitting his ideas to a manufacturer. Indeed many manufacturers will refuse to consider inventions put up to them at all unless the inventions have been protected.

The early filing of a provisional is very valuable in cases where the manufacturer introduces subsequent improvements, as the provisional will define how much of the finished manufacture is due to the inventor and how much can fairly be said to have been developed by the manufacturer.

The Patents Act contains provisions protecting inventors against others who either disclose or fraudulently take out patents themselves for unpatented inventions communicated to them in confidence by the inventor. The remedy is, however, generally an expensive one and the inventor's case difficult to prove; so that it is far wiser for him to file a provisional before disclosing his invention, in view of the possibility that otherwise interested persons might perhaps take advantage of his inexperience.

A question of some interest is the position of the paid inventor. The law says that any invention made by an employee, such as an aircraft designer, during the course of his employment shall be the property of the employer, but the actual inventor must appear as such in any patent application, otherwise the patent will be invalid. Cases have arisen in which, after dispute between the employee and employer, the employee has sought to use the patent against the employer, but the Courts have declared that the rights in the patent in such cases are the property of the employer.

The position is more difficult in the case, say, of an unskilled workman who is not paid the salary of an inventor, but chances on something useful to his employers, and the question of whether the rights in the patent belong to the workman or to the employer can only be decided on the facts of each case.

It is of great importance for a person employed in a capacity in which he may make inventions, to have a proper service agreement with his employers which will define the remuneration, if any, which he is to receive in the event of his making an invention. If he is a highly paid official, there may be no need to provide for his receiving special remuneration in respect of possible inventions, but when he is employed in a humbler capacity some such provision should certainly be embodied in his agreement to safeguard the interests of both parties.

5. *Patenting Without the Patent Agent*

In the case where the inventor is unable to afford patent agent's fees, he may write his own provisional specification and stamp the application with a £1 os. od. stamp and send the application direct to the Patent Office, 25, Southampton Buildings, London, W.C.2.

The drafting of patent specifications is, of course, a very specialised art, but although the amateur may produce a less skilful provisional specification than if he went to a patent agent to draw it, he can with a little care and forethought describe his invention in terms which will be perfectly legal, providing he describes the invention itself and does not merely set out a list of its advantages. He can also prepare a complete specification, and if he is a draughtsman in an aeronautical works he may find the preparation of the drawings not beyond his powers, especially with the very willing help which the Patent Office will give him in the directions which he may obtain by writing to the Comptroller. Those who wish to file an application for patent without incurring the costs of professional assistance should apply to the Patent Office for the official pamphlet containing instructions to applicants for patents, and after a study of these instructions most inventors may with care file applications for patents with a fair prospect of success.

One cannot, however, forget the adage that the man who is his own lawyer has a fool for a client, and without wishing to be impolite one may safely say that this adage applies equally to the inventor. The danger of filing a patent application without proper professional help is that the inventor, although he may describe his invention adequately, may claim it so narrowly that others, seeing the advantages of the invention from the specification when published, may obtain the benefit of it by making minor alterations which will avoid the over-narrow claims. Thus, to take a simple example, an inventor of a particular form of body work may claim it in his patent for application to motor cars only, thus leaving it free to others to use it for aircraft fuselages without accounting to him, whereas with a little more foresight he could have obtained claims in his patent which would have covered both applications of the invention. However, many inventors are forced to be their own patent agents and it may be better to obtain a patent of indifferent strength and narrow scope rather than allow the invention to go unprotected.

ABSTRACTS OF PATENT SPECIFICATIONS

(Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.)

Abstracts of Patent Specifications received by the Society are published in the Journal. It should be noted that these abstracts are specially compiled by Mr. W. O. Manning, F.R.Ae.S., for the Journal and are only of those actually received and subsequently bound in volume form for reference in the library. These volumes extend from the earliest aeronautical patents to date, and form a unique collection of the efforts which have been made to conquer the air.

The Council accept no responsibility whatever for the accuracy of the abstracts and in any case of doubt the full patent can be consulted when necessary in the library of the Society.

These abstracts are compiled by permission of the Controller of His Majesty's Stationery Office. Official Group Abridgments can be obtained from the Patent Office, 25, Southampton Buildings, London, W.C.2, either sheet by sheet as issued on payment of a subscription of 5s. per group volume or in bound volumes 2s. each, and copies of full specifications can be obtained from the same address, price 1s. each.

Aerodromes

420,864. *Improved Runways for Aircraft.* Boulton and Paul, Ltd., Riverside Works, Norwich, Norfolk, and North, J. D., of Hill House, Eaton, Norwich, Norfolk. Dated Feb. 24th, 1934. No. 6,099.

For the purpose of providing a runway for launching aeroplanes it is proposed to employ a horizontal platform carrying rails mounted on tractors of the caterpillar type. The wheels of the aircraft may engage the rails or there may be an intermediate trolley. As the axes of the tractors are at right angles to the track it is possible to move the runway so that it is directly into the wind by moving the tractors under their own power, each to the required amount. Arrangements are made on the tractors so that the track may be levelled and additional thrust may be imparted to the aeroplane for starting in any known way.

421,876. *Improved Wind-Direction Indicator for Aerodromes and Analogous Situations.* Hart, E. P., The Girls' High School, Pretoria, Transvaal, South Africa. Dated March 17th, 1934. No. 9,582.

This direction indicator consists of a star-shaped arrangement of lights normally buried in the aerodrome. The star has usually eight points, each being terminated by an arrow. Either incandescent or neon lights, etc., may be used, and suitable reflectors are described for each. The lights are controlled by means of a switchgear operated by a wind vane. The indicator may be coloured so as to identify the aerodrome and the switching on or off may be controlled by a light sensitive cell. The lights of the indicator may be so arranged, by means of curved covers or the like, to illuminate the aerodrome.

Aeroplanes—Construction

420,025. *Improvements in or relating to Engine Mountings for Aircraft.* The Bristol Aeroplane Co., Ltd., and Barnwell, F. S., both of Filton House, Bristol. Dated Aug. 30th, 1933. No. 24,063.

In the case of radial engines the mounting normally consists of a metal ring, bolted to the rear of the engine and attached to the fuselage of the aeroplane by means of a braced system of tubes and wires. As portions of the engine, such as carburettors, are arranged behind the ring and project beyond it they have to be dismantled before the engine can be mounted or dismounted. To obviate this difficulty it is proposed to provide a detachable portion to the ring so that the carburettors, etc., may pass through the gap provided when this is removed. This detachable portion is afterwards bolted to the remainder of the ring and may be bolted to the engine before mounting.

420,209. *Improvements in and relating to Aeroplanes with Folding Wings.* Walker, G. E., 65, Rockley Road, Sheffield, 6. Dated Feb. 22nd, 1933. No. 8,994.

This is an arrangement by which the wings of an aeroplane may be folded and unfolded from the cockpit. The wings are hinged on the rear spar close to the fuselage and are folded simultaneously by a lever and rod gear operated by a nut on a screwed rod, which latter is rotated by the pilot. A type of scissors gear is also incorporated so that the control stick can be locked when the wings are folded and unlocked when they are unfolded, the operations taking place automatically. The locking of the wings in the unfolded position is also carried out automatically. The joint in the wing extends diagonally forwards so that the long front spar in the stub end enables a reasonable wheel base to be provided.

420,184. *Improvements in Aeroplane Wings and Like Structures.* A.T.S. Co., Ltd., 3/4, Clement's Inn, Strand, London, W.C.2, and Folland, H. P., Gloster Works, Hucclecote, Gloucester.

In the case of a metal wing of the normal type, it is proposed to attach the ribs to the spars by dowells instead of by friction and to provide means by which the ribs may be removed without dismantling the wing. On each side of each spar the rib carries vertical members which carry the dowells, the latter projecting into suitably supported holes in the booms of the spar. The section of the rib over the spars may be removed for dismantling when the vertical rib members may be swung aside thus releasing the dowells. The rib section and the vertical rib members may be secured by the same rivet. Alternative methods of carrying out the arrangement in which the dowells are fitted on the spar and holes are in the rib members are described and fittings may be used as an alternative to piercing the spar.

420,138. *Improvements in or relating to the Building of Aircraft.* Avions Rene Couzinet, 3-5, Boulevard de Levallois Prolonge, Ile de la Grande Jatte, Levallois-Perret (Seine), France. Dated Feb. 21st, 1933. No. 5,320. The application for a patent has become void.

This specification relates to a method of attaching aeroplane wings to a fuselage, the object being to obstruct, as little as possible, the space within the fuselage. It is proposed to use a narrow girder of great depth, rigid with the wing inserted in the fuselage. As far away as is possible from this girder there is another point of attachment which is only subject to shear stresses. A special application of the arrangement is proposed for seaplanes in which a portion of the structure necessary for the support of the floats is incorporated in the device.

420,146. *Improvements in and relating to Aircraft.* Walker, G. E., 65, Rockley Road, Sheffield, 6. Dated Feb. 22nd, 1933. No. 5,415.

It is proposed to construct aeroplane fuselages of four stamped sections connected longitudinally by bolted or welded flanges. Interposed between the opposite flanges, both horizontally and vertically, are stiffening members bolted to the flanges. These may be adapted to carry the control mechanism, etc. All parts may be corrugated if desired, all corrugations and flanges lying in the direction of flight.

420,120. *Improvements in or relating to the Undercarriage of Aircraft.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Ordidge, F. H., Soircraft, Croft Gardens, Ruislip, Middlesex. Dated Oct. 26th, 1933. No. 29,737.

In the case of retractable undercarriages which fold backwards, it is not normally possible to house the wheels completely in the plane owing to the limited depths of the latter. It is proposed to obviate this by causing the wheel to turn as it moves backwards so that, when housed, it will lie flat in the wing. The rear support of the wheel chassis is partially forked so as to permit the wheel to be housed between the forks. The rotation of the wheel is effected by means of a bevel gear in the wing which may be disconnected if it is desired to lower the chassis so as to permit the aeroplane to be handled in a low hangar.

421,223. *Improvements relating to Tail Wheels for Aircraft.* Dowty, G. H., 17, Lansdown Crescent, Cheltenham, Gloucester. Dated, June 20th, 1933, No. 32,788; and Jan. 31st, 1934, No. 3,274.

This specification refers to a castoring tail wheel which, when unloaded or lightly loaded, may align itself and which under load may be capable of turning out of alignment, with or without some degree of restraint. The tail wheel is mounted in a fork carried by a tubular member which in its turn is carried by a further tubular member attached to the aircraft. The relative sliding of these members is controlled by springs and by a frictional device consisting of split rings which are coned so that they distort radially under load. This device also brakes the castoring effect. A spring acting on a free cam controls the self-centring.

Aeroplanes—Control

419,559. *Aeroplane Wings.* L.P.R. Co., 277, Park Avenue, City and State of New York, U.S.A. Convention date (U.S.A.), Oct. 11th, 1932.

In wings provided with slots it is proposed to arrange the slot in a fixed position forward of the wing and to close the gaps between the slot and the wing by means of flaps. These flaps are connected by means of a flexible diaphragm, which, with the flaps, forms an airtight compartment. Holes are provided in the leading edge of the slot communicating with the airtight compartment in such a position that, in high speed flight, pressure is produced in the compartment thereby closing the gaps in the wing by the flaps, while at low speeds the air is withdrawn from the compartment and the flaps open. Drainage holes are provided and arrangements for warming may be made so as to prevent freezing.

419,568. *Improvements in Automatic Stabilisers for Aeroplanes, Vessels, Torpedoes and the Like Craft.* Gianoli, M. L., 15, Rue Louis-Philippe, Neuilly-au-Seine, France. Convention date (Germany), Dec. 31st, 1932.

It is stated that apparatus which detects a variation from, say, the course of the craft and which acts on a control for resuming the course, produces pendular oscillations of the craft controlled. It is therefore proposed that the position of the control should be affected by the sign of the deviation (positive when the deviation increases, negative when it diminishes), so that for one and the same

angle of deviation the angle of the control must be, for a negative deviation, materially smaller than for a positive deviation. The apparatus proposed is a complicated system of levers operated by wind vanes and acting on the control member of the craft.

419,687. *Improvements in or relating to the Controlling Mechanism of Aeroplanes.* Fairey, C. R., Cranford Lane, Hayes, Middlesex. Dated, Oct. 26th, 1933. No. 29,734.

In the case of aircraft having variable camber wings and in which, normally, a connection is made so that variation of angle of incidence of the tail plane takes place automatically and concurrently with the variation of the camber of the wings, it is proposed to arrange that either of these variations may be carried out independently of the other. A hand wheel is provided which normally effects, on rotation, the variation of camber, and which, by means of a separate pulley, operates wires which in turn operate a screwjack on the tail plane, which moves the rear spar and effects a variation of the incidence. This separate pulley is arranged to be clutched in or out. Alternatively, the two pulleys may be controlled by gear wheels connected by an intermediate gear wheel, which latter may be moved out of gear.

419,748. *Improvements in or connected with Balancing Means for Control Surfaces of Aircraft.* Vickers (Aviation), Ltd., and Wallis, B. N., Weybridge Works, Byfleet Road, Weybridge, Surrey. Dated May 10th, 1933. No. 14,536.

In the case of aircraft having the control surfaces provided with rear flaps for the purpose of assisting in the angular displacement of the surfaces, it is stated that the ordinary arrangement results in producing an undesirable turning force at small angles of displacement. It is also proposed to use the flap for trimming purposes. In the normal arrangement the rod operating the flap is attached to a fixed bracket so that variation of the angle of the main control results in a continuous angular adjustment of the flap. It is proposed to operate this rod from a crank mounted on a separate shaft which is driven by gear wheels from the main control axis. It is so fitted that over the first period of the movement of the main control surface the flap remains in alignment with the main control surface, but that when the crank approaches a horizontal dead centre the flap is progressively operated in the desired direction. In an alternative arrangement an idle pinion is introduced to increase the rate of angular adjustment of the crank arm which is carried by a Geneva movement, and the control surface can be trimmed in flight by mounting the crank arm so that it can be rocked by a Bowden wire control.

420,928. *Improvements in or relating to Aileron Gear for Aircraft.* The Blackburn Aeroplane and Motor Co., Ltd., Seaplane Base, Brough, Hull, East Yorks, and Bumpus, F. A., Elloughton, Brough, Hull, East Yorks, and Bolton, F., Coldicott, Barrow Lane, Hessle, East Yorks. Dated, Aug. 19th, 1933. No. 23,134.

This specification describes a mechanism by means of which the ailerons of an aircraft may be pulled down or up simultaneously for the purpose of altering the camber of the wing, and at the same time be moved differentially for control purposes. The mechanism is carried in the control stick and consists of a manually-operated bevel gear operating a vertical shaft fitted with a screw and contained in the control stick. On operating the bevel gear the shaft moves up and down and operates a toggle gear at the bottom which operates the ailerons simultaneously. The upper end of the shaft carries an indicator which indicates the position of the ailerons. The ailerons are operated differentially by moving the control stick in the usual manner.

422,813. *Improvements in Control Apparatus for Aeroplanes and other Dirigible Objects.* Meredith, F. W., Royal Aircraft Establishment, S. Farnborough, Hants, and Cooke, P. A., Air Ministry, Kingsway, London. Dated Dec. 19th, 1933. No. 34,695.

It is proposed to control an aeroplane laterally by the use of a universally mounted gyroscope with a horizontal axis with the aid of a servo-motor. The centre of gravity of the gyroscope lies below the fore and aft axis of suspension of the outer gimbal ring, and it is so arranged that during steady curved flight the rate of precession of the inner gimbal, due to centrifugal force on a pendulously weighted part of the gyroscope is equal to the rate of turn of the aeroplane. When the inner ring precesses relatively to the outer ring from a normal position a torque is applied between the outer ring and the frame of a corresponding sign to the relative movement of the rings in a direction to produce a counter precession of the inner ring and restoring means for applying a torque between the two rings when the inner ring precesses relatively to the outer ring in the opposite direction to the direction of precession. The restoring means is a spring connected between the inner and outer rings.

422,493. *Automatic Aerodynamic Stabiliser for Aircraft.* Bemberg, O. E., 28, Rue Emile Menier, Paris, France. Convention dates (France), July 22nd, 1933, and July 10th, 1933.

In this device the automatic stabilisation is controlled by means of a special arrangement supported externally to the aeroplane, possibly above the planes. This special arrangement consists of a rod carrying at its forward end a system of radial planes and at its rear end a similar member. This is pivoted on a universal joint near the forward end of the device, the universal joint being attached to the aeroplane, possibly by means of a post. The movements of this device from the line of flight of the aeroplane are used to correct any deviations of the latter by means of a servo-motor device operating the controls or by direct connection to the controls.

421,766. *Improvements in or relating to Automatic Steering Devices.* Askania-Werke Aktiengesellschaft, Vormals Controlwerkstad Dessau und Carl-Bomberg-Friedman, Unrukstrasse 1, Dessau, Germany. Convention date, Feb. 15th, 1933.

It is proposed to provide an automatic controlling device comprising a rudder motor for effecting the steering and controlled from means responsive to angular deviations or angular movements of the craft through a force controller or relay having relatively movable parts, the operation of the motor being dependent upon the magnitude of the relative displacement of the said parts, return or follow up mechanism for said force controller or relay controlled by said rudder motor or rudder and means independent of external influences for yielding by urging said relatively movable parts to the position of zero relative displacement at which the motor is not operated. The force controller consists of a jet tube, movable before receiving nozzles which are mounted in a movable block or frame connected to the rudder, the jet tube and block being constrained to the zero position by means of springs.

Aeroplanes—General

420,784. *Improvements in or relating to Flotation Gear for Aircraft.* Dagnall, R. F., 17 Stoke Road, Guildford, Surrey, and Lambert, J. G., 20a, Granby Place, Leicester. Dated April 16th, 1934. No. 11,383.

Reference is made to Specification 410,489, which describes a method of inflating airbags on aircraft from a bottle containing compressed gas. The inflation is carried out automatically as electrical contact is made between two

copper plates by immersion, thus causing the flow of a current which explodes a cartridge. This cartridge propels a plunger which in its turn operates a cutter which cuts a hole in a diaphragm, thus allowing the gas from the cylinder to enter the bags. It is stated that trouble has arisen owing to the cutter being driven back by the gas pressure, thereby sealing the hole it has made. It is proposed to obviate this difficulty by using a pawl operating with a spring-controlled ratchet, thereby preventing the return of the cutter. Means for manual control are provided.

419,539. *Improvements in or relating to Aeroplanes.* Mobbs, R. O., Trading Estate, Slough, Bucks. Dated June 2nd, 1933. No. 15,927.

It is proposed to provide an emergency means of escape from the fuselages of passenger aircraft by providing a sliding hatch carried by a frame attached to the fuselage which can be released by movement of a handle operating the hatch. The sliding hatch is free from any projection which would be liable to catch the clothing of those escaping and is designed to be rain proof.

421,178. *Improvements in Aircraft.* Ockenden, A. G., 10, Midholm, Wembley Park; Neil, J. R., 40, Ealing Road, Wembley; Ockenden, M., 10, Midholm, Wembley Park. Dated May 17th, 1933. No. 14,248.

This specification refers to aircraft possessing an outer rotatable casing which is provided with a spirally arranged propelling device and surrounding an inner shell containing the load, power, etc. The propelling device resembles a screw thread, and it is stated to produce a vacuum in the front of the machine which is thereby drawn through the air. The aircraft is to rise vertically from the ground, to assume a horizontal position when a desired height is reached and to land in a vertical position. Its rear end is provided with means to support it in a vertical position and is cushioned. The mechanism required is described in detail.

422,621. *Improvements in Arrangements for Starting Flight Requiring no Gliding.* Nishi, H., 878, Oaza-Kimüdera, Kimüdera-Mura Kaisa-Gun, Wakayama-Ken, Japan. Convention date (Japan), Aug. 22nd, 1933.

It is proposed to embody in an aeroplane fuselage an apparatus for producing direct lift. The apparatus consists of an upright cylindrical air duct which is considerably flared at its lower end through which air is driven by two concentrically mounted propellers revolving in opposite directions. In the lower end of the duct the air impinges on an annular aerofoil which consists of a ring possessing, radially, an aerofoil section. It is stated that the ring will lift 100 kilogrammes per square metre in an air current of 30 metres per second. Another similar ring is provided, the air current for which is produced by compressed air from a bottle.

422,188. *An Improved Convertible Aeroplane and Motor Road Vehicle.* Nystrom, S., Stjärnorp, Linköping, Sweden. Dated April 8th, 1933, No. 10,545; Jan. 10th, 1934, No. 911; and Jan. 10th, 1934, No. 912.

The arrangement described consists of an aeroplane with wings which fold backwards which is provided with wheels for road use, in addition to a folding chassis. The rear road wheels may be driven from the main engine or from an auxiliary engine, and, if both engines are carried, either may drive the propeller. The wings may be telescopic if necessary for folding.

Airscrews

420,313. *Improvements relating to Multi-Engined Aeroplanes.* Stieger, H. J., General Aircraft, Ltd., Croydon Aerodrome, Surrey. Dated June 14th, 1933. No. 16,987.

In multi-engined monoplanes it is proposed to arrange that the discs of the two propellers nearest to the fuselage shall be as adjacent to each other as possible. It is proposed that these discs shall come together beneath the fuselage and the fuselage may be hollowed in their vicinity. The drawing shows a low-winged monoplane in which the wing roots slope sharply up to the fuselage and the two wings are, in addition, connected by a member passing before the fuselage.

421,889. *Improvements in Gearing for Propellers.* Rowledge, A. J., Ellerslie, Trowells Lane, Mickleover, Derby, England; Ellor, J. E., Grandell, South Drive, Chain Lane, Littleover, Derby, England; Rubra, A. A., Red Roofs, Carlton Avenue, Derby, England. Dated June 23rd, 1933. No. 17,874.

This specification describes a method by which two propellers, rotating in opposite directions at the same speed, may be mounted concentrically and driven by a single engine. The propeller shafts are in line with the engine crankshaft. The gear proposed is of the sun and planet type, in which each planet pinion shaft carries three pinions. One of the latter engages the reaction wheel, the other two engaging pinions on the respective propeller shafts. By suitably proportioning these two latter pinions the shafts may be driven in opposite directions at the same speed of rotation. The reaction wheel may be either internally or externally toothed and an alternative scheme is described using bevel gears to produce the same effect.

Armament

420,160. *Improvements in Armed Turret Carrying Sundry Materials and adapted to be Lowered from an Aircraft by Means of a Parachute.* Count G. E. Ilia, 9, Via S. Valentino, Rome, Italy. Convention date (Italy), Dec. 13th, 1932.

It is proposed to drop an armed turret from aircraft for war purposes. The turret may contain a number of persons and also quick-firing guns, bomb throwers, ammunition, fire jets, or medical materials, etc., and may be provided with its own means of locomotion. It may be adapted for dropping on land or water. The parachute is automatically detached on landing and, if it collapses on the turret, may be burnt with a petrol flame.

Autogiros

420,322. *Improvements in and relating to Aircraft with Freely Rotative Wings.* Juan de la Cierva, Bush House, Aldwych, London, W.C.2. Dated Aug. 5th, 1933. No. 22,105.

In the case of autogiros, where means are provided for applying a starting torque to the rotor for the purpose of imparting an initial rotation prior to flight, the maximum torque so transmissible to the rotor being less than that required for helicopter flight, the power transmission means are adapted to impart to the rotor an initial rotational speed considerably in excess of the mean rotative speed in flight, and means are provided for substantially reducing the rotational drag of the rotor during the application of the starting torque and for utilising the excess kinetic energy stored in the rotor by virtue of its excess speed to generate a thrust sufficient to raise the aircraft off the ground by changing the pitch angle of the rotor blades so that during the application of the starting torque the pitch angle may be decreased. The means for changing the pitch angle operate automatically according to the torque applied to the rotor. The means for changing the pitch angle may operate automatically in response to changes of centrifugal force, or both. Constructional details are described.

417,504. *Improvements in Aircraft.* N.V. Instituut voor Aero and Hydro-Dynamik, 19, Reguliers-gracht, Amsterdam, Holland. Convention dates (Germany), Feb. 2nd, 1932; Feb. 2nd, 1932; Aug. 13th, 1932.

In the case of autogiro aircraft it is proposed to hinge the rotating wings to a lever hinged to the vertical shaft instead of to the shaft itself. This lever is hinged to the shaft in the centre, the ends of the lever carrying the wings. There may be constructed four-bladed rotors on this principle, each pair of wings having its own lever, or the centre joint may be universal.

422,212. *Improvements in and relating to Rotor Blades for Aircraft with Auto-Rotative Sustaining Rotors.* de la Cierva, J., Bush House, Aldwych, London, W.C.2. Convention date (U.S.A.), July 15th, 1932.

In the case of autogiro rotors it is stated that it has been found desirable to stiffen the rotating wings so as to prevent vibration and also to simplify the construction. It is therefore proposed to construct the blades of solid drawn metal tube of appropriate section, and to mount them to the hub by a much wider bearing than previously. Means are described by which the tip form of the blade may be shaped as desired and a stop is provided to prevent the blades dropping when not rotating, in place of the wires sometimes used. The tubular blades are proportional to take all stresses and special means are described to ensure that the connection between the blades and the hub fitting is adequate.

Engines

420,331. *Improvements in or relating to Evaporative Cooling Systems for Aircraft Engines.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Lyon, G., Ranmoor, Fulmer Road, Gerrards Cross, Bucks. Dated, Oct. 27th, 1933. No. 29,909.

It is proposed to circulate the engine cooling fluid from the engine to a separator where the vapour is separated from the fluid, the fluid being circulated by a pump. The vapour, after passing through several condensers, is condensed and returns to the system via a second pump. The vapour from the separator is passed, first to a header tank on the leading edge of the wing, then to two condensers constituting the forward portions of the lower surface of the wing, then to two further condensers forming a part of the upper surface of the wing immediately over the previous condensers, then to a condenser on the upper surface of the central portion of the wing, then to a tank via a pressure relief valve, which tank is vented. All condensers are provided with pipes conducting the condensed fluid to the second pump. Various constructions are described, and there are also details of constructive methods.

421,761. *Cowling for Aircraft Engines.* Armstrong-Siddeley Motors, Ltd., and Reynolds, R., both of Armstrong-Siddeley Works, Park Side, Coventry, Warwickshire. Dated Dec. 13th, 1933. No. 35,054.

This specification describes a cowl for air-cooled radial engines which may approximate in shape to either an N.A.C.A. cowl or to a Townend ring, but which carries internally a radial plate extending to the cylinder heads, the object of which is to force the air to flow round the engine cylinders. To assist this action a cylindrical band parallel to the axis of the engine may be attached to the inner edge of the plate.

421,438. *Improvements in and relating to Planetary Reduction Gears for Radial Aeroplane Engines.* Compagnia Nazionale Aeronautica, 23, Via Sistina, Rome, Italy. Convention date (Italy), April 20th, 1934.

It is pointed out that the valve control of radial engines is usually effected by a ring carrying a number of cams which rotates slowly with regard to the

engine speed and which is usually driven by a separate train of gears. It is proposed to drive this cam ring from the propeller reduction gear. This latter gear, which is of the normal sun and planet type, has the shafts carrying the planet wheels lengthened so that each shaft carries an additional gear wheel. This latter gear wheel engages with a toothed ring carrying the cams and the latter can be driven at the desired speed by suitably proportioning the gears. Modifications of the main principal are described and illustrated.

Miscellaneous

421,528. *Device for Producing Helical Whirls.* Loftheim, T. B., Vinderen, Oslo, Norway. Dated March 20th, 1933. No. 8,409.

This device is intended to produce disturbances in fluids of the type described as a wind spout, by which term it seems that a whirlwind is meant. It is suggested that the device may be used as a highly efficient pump for fluids, or, if it is fitted to the nose of an airship or to the boss of a propeller, it is said to materially reduce the resistance of such bodies. The device in its simplest form consists of a pointed metallic rod in which the portion from the point to the full diameter of the rod is deeply grooved, leaving a number, usually four, of curved vanes. When this is rotated it is stated that air issues spirally from the portion of the vanes remote from the point. Various modifications of this device are described and diagrams are given showing how the arrangement can be used as a pump.

Model Aircraft

419,498. *Improvements in Toy Aeroplanes.* Marcus, E., 38, Rue Duret, Paris, France. Convention date (France), March 11th, 1933.

It is proposed to produce toy aeroplanes which may resemble any type of civil or military aircraft by cutting and folding a sheet of paper, etc., which may also be coloured. These are provided with a balance weight in the forward part for balancing, etc. Drawings and descriptions are given of the shapes of material necessary to produce the toy aeroplanes and of the methods of joining the parts.

Parachutes

420,059. *Improvements in or connected with Parachute Equipment.* Irving Air Chute of Great Britain, Ltd., Icknield Way, Letchworth, Herts. Dated, July 26th, 1934. No. 21,927.

This specification refers principally to parachutes of the type which can be freed automatically by means of a line connection to the aircraft and non-automatically by means of a manual release. There are four flaps, the opposite one carrying two and one eyelet respectively, so that they may be maintained closed by two egg-shaped pins, drilled at each end. The holes in the pins carry locking wires which are attached respectively to the cord for automatic release and to the cord for manual release. The cord for automatic release is covered normally by an additional flap and is provided with a snap hook. Elastic cords are provided for facilitating opening. Alternative shapes for the two pins are described and illustrated.

420,048. *Improvements in Releasing Means for Parachutes.* Givry, G., 103, Avenue de Gennevilliers, Colombes (Seine), France. Convention date (France), April 24th, 1934.

The parachute referred to is of the automatically opened type operated by a cord attached to the aircraft. This cord is attached to a spindle on the parachute which has a ball head and is normally retained in a hole in a rigid cylindrical member by means of spring controlled balls. The container has a rigid base and

an extractor is provided, made in star form of thin spring steel covered with fabric.

Pilots and Piloting

422,104. *Training and Testing Device for Pilots.* Rose, L. S., Box 414, Rantoul, Illinois, U.S.A. Dated June 19th, 1934. No. 18,190.

This specification describes an apparatus attached to the ground which can be caused to imitate the attitudes of an aeroplane in the air. It is intended for flying instruction, for checking piloting ability, or for amusement purposes. It consists of a dummy aeroplane mounted within tubular frames similar to the gimbals of a compass. These tubular frames carry compressed air or other fluid to various positions on the dummy aeroplane where it is allowed to escape, thereby producing reactions on the dummy aeroplane. Valves controlling the escape of the air are arranged to be controlled by dummy aeroplane controls, so that the dummy aeroplane can be manœuvred in a manner similar to an aeroplane in flight.

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Professional Classes Aid Council: Lord Sempill.

Membership

The membership of the Society shows for the year 1934 a satisfactory increase over 1933. The following table gives the membership in detail for 1934, and the figures in brackets the corresponding figures for 1933. In 1932 there was a *decrease* of 25 over the 1931 figures, in 1933 an increase of 42 over 1932, and in 1934 an increase of 96 over the 1933 total. The increase, as in the previous year, has been most noticeable in the Associate Fellowship and Studentship grades. For the first time in the history of the Society the total membership, excluding the Branches, has reached 1,500. In 1925 the membership of the Society was 630.

	No. of Members.	Honorary & Life Members.	Suspended.	Total.
Fellows	134 (133)	22 (22)	1 (1)	157 (156)
Members	50 (51)	—	2 (2)	52 (53)
Associate Fellows ...	458 (428)	5 (5)	17 (17)	480 (450)
Associate Members ...	98 (89)	—	11 (14)	109 (103)
Associates	177 (166)	3 (3)	14 (15)	194 (184)
Companions	99 (100)	10 (10)	6 (7)	115 (117)
Founder Members ...	25 (24)	1 (1)	—	26 (25)
Students	352 (302)	—	25 (24)	377 (326)
Temp. Hon. Members ...	—	21 (20)	—	21 (20)
	1393 (1293)	62 (61)	76 (80)	1531 (1434)
Less Joint Members ...	28 (27)			28 (27)
	1365 (1266)	62 (61)	76 (80)	1503 (1407)

Donations

The Council have to thank the Air Ministry for the tenth year in succession for their generous donation of £250 to the funds of the Society, and the Society of British Aircraft Constructors (also for the tenth year in succession) for their generous donation of £250. It is very largely due to the grants of the Air Ministry and the Society of British Aircraft Constructors that the Council has been able to maintain its policy of publishing more and more scientific and

technical matter, and to keep the Journal in the forefront of aeronautical technical journals of the world. Without these grants, indeed, the Society would have found it difficult to maintain its high standard.

Endowment Fund

The table below gives the progress of the Endowment Fund:—

	£	s.	d.
December, 1926	575	0	0
December, 1927	597	2	0
December, 1928	1,047	18	0
December, 1929	1,077	6	0
December, 1930	1,265	10	0
December, 1931	1,935	10	0
December, 1932	2,196	2	0
December, 1933	9,716	19	5
December, 1934	10,131	14	11

The Council urge every member to bear in mind the objects of the Endowment Fund, which, under the Endowment Fund Trust Deed, is to be specifically devoted to providing the Society with its own building and lecture theatre. The Council keep the Fund continually in their minds and take every opportunity of adding to it. The acquisition by the Society of its own building and lecture theatre will add considerably to the prestige of the Society and will thereby be of very real value to every member.

Library

It is now eleven years since Mr. J. E. Hodgson, Hon. F.R.Ae.S., became Honorary Librarian to the Society, and the Council have to thank him for the expert advice which he has given from time to time. Mr. Hodgson acts as the Society's representative at Council Meetings of the National Central Library for Students and the Association of Special Libraries and Information Bureaux, both of whom are doing valuable work.

The Society's collection of slides is now approaching 4,000, covering every aspect of aviation. The Council wish to thank those many members and firms who have helped during the year to make the collection representative and up to date. Their willing help and co-operation have gone a long way to fill in the many gaps which still remain in what must now be regarded as one of the finest collections of aeronautical slides in the world.

The Society has also a large collection of photographs which have been very considerably added to during the year. These photographs have been generously given to the Society from members and firms, both in this country and abroad, so that it is now a unique pictorial record of aviation.

The Council hope that any member who may have any historical items of aeronautical interest which they find difficult in storing will look upon the Society as a suitable repository, and let the Society have them upon permanent loan. They will in this way be readily available at the Society's headquarters and be of interest and use to all members.

During the year it has become increasingly obvious that the object of the Council to help those who wish to obtain any information about aviation is being fulfilled. The number of inquiries, both technical and historical, has greatly increased over the previous year. The founding of the Technical Index and other indexes a few years ago, has enabled the great majority of these inquiries to be answered the same day. These indexes at present number some 20,000 cards.

Wilbur Wright Memorial Lecture

The Wilbur Wright Memorial Lecture for 1934 was delivered before a distinguished audience at the Science Museum, South Kensington, by Professor B. Melvill Jones, A.F.C., M.A., F.R.Ae.S., Francis Mond Professor of Aeronautical Engineering, Cambridge University, on "Stalling." The lecture was preceded by the Council Dinner and followed by a conversazione. Before the lecture was delivered the various medals and prizes which have been awarded during the year were presented. The report of the lecture and the conversazione appeared in the Journal for September, 1934.

Lecture Programme

A full list of lectures delivered before the Society, and of the principal lectures delivered before the Branches, were given in the Journal for December, 1934. In addition, the following lectures have been delivered or arranged for during the remainder of the present session:—

January 7th.—Mr. F. Snowden Gamble, "Imperial Air Routes."
February 8th.—Mr. W. C. Clothier, M.Sc., "Ice Formation in Carburettors."
February 22nd.—Mr. L. P. Coombes, B.Sc., A.C.G.I., "Research in the R.A.E. Tank."
March 1st.—Mr. E. L. Bass, "Fuels for Aircraft Engines."
March 5th.—Dr. H. Gough, F.R.S., and Dr. Desch, F.R.S., "Problems of Cold Presswork." (Joint meeting with the Inst. of Aut. Engs. and other bodies.)
March 15th.—Senor de la Cierva, F.R.Ae.S., "New Developments in the Autogiro."
March 29th.—Squadron Leader H. G. Brackley, D.S.O., D.S.C., F.R.G.S., "Piloting Commercial Aircraft."
April 12th.—Captain G. de Havilland, C.B.E., F.R.Ae.S., "Commercial Aircraft."
May —.—Wilbur Wright Lecture.

Lectures before the Branches

January 3rd (Yeovil Branch).—"Compression Ignition Engines," by Mr. A. H. R. Fedden, M.B.E., M.I.A.E., M.S.A.E., F.R.Ae.S.
January 3rd (Gloucester and Cheltenham Branch).—"High Duty Alloys," by Mr. W. C. Devereux, A.F.R.Ae.S.
January 17th (Coventry Branch).—"The Autogiro," by Senor de la Cierva, F.R.Ae.S.
January 17th (Yeovil Branch).—"Small Oil Engines for Road Transport," by Mr. H. O. Farmer, B.Sc., M.I.A.E.
January 24th (Gloucester and Cheltenham Branch).—"The Autogiro," by Senor de la Cierva, F.R.Ae.S.
January 31st (Yeovil Branch).—"The Autogiro," by Senor de la Cierva, F.R.Ae.S.
January 31st (Gloucester and Cheltenham Branch).—"Airport Development," by Squadron Leader Nigel Norman, F.R.Ae.S.
February 14th (Gloucester and Cheltenham Branch).—"Metal Construction," by Mr. H. J. Pollard, A.F.R.Ae.S.
February 21st (Coventry Branch).—"Aeroplane Structures," by Major H. N. Wylie, B.Sc., M.B.E., F.R.Ae.S.
February 21st (Yeovil Branch).—"Turbulence," by Mr. E. F. Relf, A.R.C.Sc., F.R.Ae.S.
February 28th (Gloucester and Cheltenham Branch).—"Magnesium Alloys," by Dr. L. Aitchison.

March 14th (Gloucester and Cheltenham Branch).—" Some Pioneers of the Aeroplane," by Mr. J. E. Hodgson, Hon. F.R.Ae.S.
March 14th (Yeovil Branch).—" Test Flying," by Mr. H. J. Penrose, A.F.R.Ae.S.
March 21st (Coventry Branch).—" Blind Flying and Navigation of Aircraft without External Visibility," by Flight Lieut. H. F. Jenkins.
March 28th (Gloucester and Cheltenham Branch).—" American Design," by Captain F. S. Barnwell, O.B.E., A.F.C., F.R.Ae.S.

Students' Section

A report of the activities of the Students' Section for the Session 1933-34 was published in the December Journal.

The number of students of the Society shows a further increase over that of 1933. During the year the Council have had under consideration suggestions to enable the students to obtain greater facilities for flying, and these suggestions are now being examined by those who might be concerned with such help as might be given.

The Council wish to thank those members of the Society who have acted as Chairmen at the various students' lectures, and those firms who have co-operated to make the visits of students to their works of interest and value.

In addition to the programme published in the Journal for December, the following lectures and visits have been arranged:—

October 16th.—" Some Aspects of Aviation," by Captain P. D. Acland.
October 30th.—" Aero Engines," by Mr. R. G. Jones.
December 4th.—" Air Pilotage," by Mr. R. W. Hase.
February 5th.—Informal Discussion.
February 19th.—" Some Notes on Spinning," by Mr. R. K. Page.
March 19th.—" Steels used in Aircraft Construction," by Mr. R. L. Lickley.
April 16th.—" The International Challenge de Tourisme, 1934," by Mr. W. D. Macpherson.

The attendance at lectures has been disappointing during the early half of the Session. It is hoped that every student will make a special effort to attend lectures which are arranged for their benefit.

At the Annual General Meeting held on October 4th, Mr. R. W. Hase was appointed Honorary Secretary of the Students' Section.

Public Schools' Lectures

For the fourth year in succession lectures have been arranged before the public schools and other educational centres. As a result of the delivery of these lectures there has been a greatly increased demand for further lectures outside, and for the borrowing of slides by members for lecture purposes. On an average, during the Lecture Session of October to April, over 200 slides a week are loaned by the Society—a very remarkable testimonial in itself to the increasing value of the slide collection and to the propaganda work of the Society.

The Council wish to record their very grateful thanks for the assistance of all those members who have so willingly helped, in their own time, to make these lectures so successful. It is work of very real importance and its results are clearly seen by the increasing demand for lectures from all sources. The Council hope that every member will bear any possible lecture in mind. A number of such lectures have to be refused each year, but every effort is being made to reduce this number to a minimum.

Since the standard lectures were prepared, they have been delivered to nearly 300 schools to audiences totalling over 80,000.

The following is a list of the standard lectures that have been prepared:—

1.	The History of the Aeroplane	36 slides.
2.	The Aeroplane and its Uses	36 ,,
3.	Seaplanes and Flying Boats	46 ,,
4.	Training the Royal Air Force Pilots	43 ,,
5.	How an Aeroplane is Made and Flies	51 ,,

A sixth lecture, entitled " Imperial Air Routes," is in course of preparation.

All these lectures are complete in themselves and ready for delivering, so that the lecturer has no actual preparation to make.

In addition to the list published in the December Journal, the following have been arranged for, or delivered, in 1935:—

January 21st.—East Boldon, Newcastle-on-Tyne, Mr. J. Bell, A.R.Ae.S.I.
January 22nd.—Junior Imperial League, Mr. E. W. Roberts.
January 26th.—Herne Bay College, Mr. E. W. Roberts.
January 28th.—Nottingham High School, Mr. G. R. Irvine, A.M.I.Ae.E.
January 28th.—Itchen Secondary School, Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S., M.I.Mech.E., M.I.N.A.
January 29th.—King Edward VI School, Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S., M.I.Mech.E., M.I.N.A.
January 29th.—Epsom College, Captain J. Laurence Pritchard, Hon. F.R.Ae.S.
January 29th.—Northampton Town and County School, Mr. G. R. Irvine, A.M.I.Ae.E.
January 29th.—Anerley Public Library, Mr. H. R. Gillman, A.F.R.Ae.S.
January 30th.—Upton College, Bexley Heath, Mr. E. W. Roberts.
January 31st.—Peter Symond's School, Winchester, Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S., M.I.Mech.E., M.I.N.A.
February 1st.—Queen Elizabeth Grammar School, Wakefield, Mr. G. C. E. Ely.
February 2nd.—Eastbourne College, Mr. G. R. Irvine, A.M.I.Ae.E.
February 5th.—Oakmount Preparatory School, Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S., M.I.Mech.E., M.I.N.A.
February 6th.—Bilston Education Committee, Captain J. Laurence Pritchard, Hon.F.R.Ae.S.
February 8th.—City of Oxford School, Mr. A. F. Houlberg, A.M.I.Ae.E.
February 9th.—Highgate School, Mr. H. T. Winter.
February 20th.—Wrekin College, Major T. M. Barlow, F.R.Ae.S.
February 20th.—Willaston School, Mr. G. R. Irvine, A.M.I.Ae.E.
February 20th.—Wellingborough School, Lieut.-Comdr. the Hon. J. M. Southwell, A.F.R.Ae.S.
February 21st.—King's School, Chester, Mr. G. R. Irvine, A.M.I.Ae.E.
February 21st.—Woolwich Engineering Society, Mr. R. A. Wilmshurst.
February 22nd.—Durham School, Mr. E. G. Richardson, B.A., D.Sc., Ph.D.
February 22nd.—Mostyn House School, Mr. G. R. Irvine, A.M.I.Ae.E.
March 2nd.—Herne Bay College (Juniors), Mr. E. W. Roberts.
March 5th.—Birkenhead School, Captain J. Laurence Pritchard, Hon. F.R.Ae.S.
March 5th.—Hillingdon Boys' School, Mr. J. T. Morton, A.M.I.Ae.E.
March 6th.—Rossall School, Captain J. Laurence Pritchard, Hon.F.R.Ae.S.
March 14th.—Chiswick Public Library, Captain J. Laurence Pritchard, Hon.F.R.Ae.S.
March 17th.—Woodford House School, Birchington, Mr. E. W. Roberts.

Branches

The year 1934 has been a better one for the Branches than 1933. Much of that improvement is due to the energy and enthusiasm of the Chairmen, Committees and Secretaries of the Branches, who have done much to prepare interesting lectures for their members. Many of these lectures are now published in the Journal as being of interest and use to all members of the Society. The Council wish to thank all those concerned, officials and lecturers, for the work which they have done.

The following is a list of Branches and their addresses:—

Bristol.—Honorary Secretary: H. Yendall, 76, Redcatch Road, Knowle, Bristol, 4.

Coventry.—Honorary Secretary: P. V. Lamarque, A.F.R.Ae.S., Sherborne House, The Avenue, Whitley, Coventry.

Gloucester and Cheltenham. — Honorary Secretary: F. B. Ford, A.F.R.Ae.S., St. Margaret, Brockworth, Gloucester.

Hull and Leeds.—Secretary: G. B. Fenton, A.F.R.Ae.S., Glen-Affric, 1, County Road, Willerby New Road, Hull.

Manchester.—Secretary: J. A. E. Waterfall, "The Moorelands," Derby Road, Weaste, Salford, 6.

Yeovil.—Secretary: V. S. Gaunt, M.I.Ae.E., Westland Aircraft Works, Yeovil, Somerset.

Australian.—Secretary: J. V. Connolly, A.F.R.Ae.S., Science House, Gloucester and Essex Street, Sydney, Australia.

Ottawa Aeronautical Section.—Secretary: Squadron Leader A. Ferrier, R.C.A.F., M.C., B.Sc., D.I.C., A.F.R.Ae.S., Department of National Defence, Slater Street, Ottawa.

Cambridge University Aeronautical Society (Affiliated).—Secretary: P. Shaw, Clare College, Cambridge.

Montreal Aeronautical Section. — Secretary: 2,050 Mansfield Street, Montreal.

President

Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.I.Ae.E., M.P., was elected President of the Society for the year 1934-35 at the Council Meeting held on May 8th, 1934, and took office at the opening meeting of the 1934-35 Session of the Society on October 18th, 1934.

Vice-Presidents

The following were elected Vice-Presidents of the Society for the year 1934-35, at the Council Meeting held on May 8th, 1934:—

Mr. H. E. Wimperis, C.B.E., F.R.Ae.S.
Sir John D. Siddeley, C.B.E., F.R.Ae.S.

Journal

There has been an increase in the circulation of the Journal in 1934 over 1933. The revenue from outside sales has been maintained, but there has been a small increase in the total net cost (1.9 per cent.) due to a decrease in the revenue received from advertisements. Steps are being taken during the coming year to increase the advertisement revenue.

The Journal is not only circulated to members all over the world, but it is widely subscribed to by foreign governments, firms and organisations for the use of their members, and so forms one of the finest aeronautical advertising mediums, as it goes directly to those who are most interested.

(Continued on page 258)

AERONAUTICAL

Balance Sheet,

	£ s. d.	£ s. d.	£ s. d.
Share Capital—			
Authorised—40 Shares of 1/- each	... ...	2 0 0	
Issued—21 Shares of 1/- each	... ...	1 1 0	
Less—Calls in arrear	... ...	1 1 0	
Pilcher Memorial Fund—			
Capital Account—As at 31st December, 1933		99 14 0	
Income Account—Balance at 31st December, 1933 ...	32 3 0		
Less Excess of Expenditure over Income for year to date	0 19 4	31 3 8	
			130 17 8
Usborne Memorial Fund—			
Capital Account—As at 31st December, 1933		109 2 5	
Income Account—Balance at 31st December, 1933 ...	29 13 0		
Add Surplus of Income over Expenditure for year to date	3 19 0	33 12 0	
			142 14 5
Herbert Akroyd Stuart Fund—			
Capital Account—As at 31st December, 1933		688 19 0	
Income Account—Balance at 31st December, 1933 ...	133 5 7		
Less Excess of Expenditure over Income for year to date	2 7 0	130 18 7	
			819 17 7
R.38 Memorial Fund—			
Capital Account—As at 31st December, 1933		978 3 10	
Income Account—Balance at 31st December, 1933 ...	275 0 4		
Add Surplus of Income over Expenditure for year to date	36 13 10	311 14 2	
			1289 18 0
Edward Busk Memorial Fund—			
Capital Account—As at 31st December, 1933		449 6 1	
Income Account—Balance at 31st December, 1933 ...	91 2 2		
Less Excess of Expenditure over Income for year to date	3 12 3	87 9 11	
			536 16 0
Wilbur Wright Memorial Fund—			
Capital Account—As at 31st December, 1933		1298 9 9	
Income Account—Balance at 31st December, 1933 ...	91 13 5		
Add Surplus of Income over Expenditure for year to date	3 8 6	95 1 11	
			1393 11 8
Simms Gold Medal Fund—			
Capital Account—As at 31st December, 1933		250 0 0	
Less—Income Account Deficiency at 31st December, 1933	2 2 0		
Add Excess of Expenditure over Income for year to date	4 13 6	6 15 6	
			243 4 6
Royal Aeronautical Society Endowment Fund—			
Capital Account—Balance at 31st December, 1933 ...		9666 19 5	
Add Amount over, reserved at 31st December, 1933, for Legal Expenses		21 9 1	
Donations received during year		3 17 3	
Entrance Fees received during year		156 9 0	
Surplus of Income over Expenditure for year to date		284 4 9	
		10132 19 6	
Less Loss on Realisation of Investment...		1 4 7	
			10131 14 11
			£14688 14 9

We report to the Members of Aeronautical Trusts, Ltd., that we have examined the above Balance Sheet is properly drawn up explanations we have required. We are of opinion that December, 1934, according to the best of our information and the explanations given to us and as

3, Frederick's Place, Old Jewry, London, E.C.2.

19th February, 1935.

TRUSTS, LTD.

31st December, 1934.

	£ s. d.	£ s. d.
Pilcher Memorial Fund—		
£115 6s. 10d. 3½ % War Loan at cost	116 5 0	
Cash at Bank	14 12 8	
		130 17 8
Usborne Memorial Fund—		
£113 3½ % War Loan at cost	114 11 1	
Cash at Bank	28 3 4	
		142 14 5
Herbert Akroyd Stuart Fund—		
£683 1s. 0d. 3½ % War Loan at cost	698 19 0	
Cash at Bank	147 3 7	
	846 2 7	
Less—Amount owing for 1934 Award	26 5 0	
		819 17 7
R.38 Memorial Fund—		
£1048 11s. 2d. 3½ % War Loan at cost	1098 18 10	
Cash at Bank	190 19 2	
		1289 18 0
Edward Busk Memorial Fund—		
£284 4s. 2d. 3½ % War Loan at cost	284 4 2	
£217 London Transport 4½ % "A" Stock at cost	199 4 6	
	483 8 8	
Cash at Bank	53 7 4	
		536 16 0
Wilbur Wright Memorial Fund—		
£1047 6s. 7d. 3½ % Conversion Stock, at cost	800 0 0	
£550 Canada 4 % Stock, at cost	531 10 9	
	1331 10 9	
Cash at Bank	95 1 11	
	1426 12 8	
Less—Amount owing to Aerial Science, Ltd.	33 1 0	
		1393 11 8
Simms Gold Medal Fund—		
£287 16s. 1d. India 4½ % Stock, 1958/68, at cost	250 0 0	
Cash at Bank	45 4 6	
	295 4 6	
Less—Amount owing to Aerial Science, Ltd.	52 0 0	
		243 4 6
Royal Aeronautical Society Endowment Fund—		
Investments at Cost—		
£2043 19s. 8d. 3½ % Conversion Stock	1584 18 3	
£1192 13s. 0d. 3 % Local Loans	1034 15 5	
£4100 L. & N.E. Rly. 3 % Debentures	3162 6 3	
£3100 L.M. & S. Rly. 4 % Debentures	3162 19 9	
£831 2s. 0d. 3 % Conversion Stock	834 16 9	
	9779 16 5	
Cash at Bank	184 18 1	
Amount due from Aerial Science, Limited	167 0 5	
		10131 14 11
		£14688 14 9

Balance Sheet with the books of the Company and have obtained all the information and so as to exhibit a true and correct view of the state of the Company's affairs as at 31st shown by the books of the Company.

PRICE, WATERHOUSE & CO.

AERONAUTICAL

INCOME & EXPENDITURE ACCOUNTS

Pilcher

	£ s. d.
To 1934 Award	5 0 0
	£5 0 0

Usborne

To Surplus of Income over Expenditure for year carried to Balance Sheet	3 19 0
	£3 19 0

Herbert Akroyd

To 1934 Award	26 5 0
	£26 5 0

R.38

To Surplus of Income over Expenditure for year carried to Balance Sheet	36 13 10
	£36 13 10

Edward Busk

To 1934 Award	21 0 0
	£21 0 0

Wilbur Wright

To 1934 Award	50 0 0
,, Surplus of Income over Expenditure for year carried to Balance Sheet	3 8 6
	£53 8 6

Simms Gold

To 1934 Award	17 12 6
	£17 12 6

Royal Aeronautical Society

To Surplus of Income over Expenditure for year transferred to Capital Account ...	284 4 9
	£284 4 9

TRUSTS, LTD.

FOR THE YEAR ENDED 31ST DECEMBER, 1934.

Memorial Fund

	£ s. d.
By Interest on Investments (gross)	4 0 8
,, Balance of Expenditure over Income for year carried to Balance Sheet	0 19 4
	£5 0 0

Memorial Fund

By Interest on Investments (gross)	3 19 0
	£3 19 0

Stuart Fund

By Interest on Investments (gross)	23 18 0
,, Balance of Expenditure over Income for year carried to Balance Sheet	2 7 0
	£26 5 0

Memorial Fund

By Interest on Investments (gross)	36 13 10
	£36 13 10

Memorial Fund

By Interest on Investments (*less* Tax)...	17 7 9
,, Balance of Expenditure over Income for year carried to Balance Sheet	3 12 3
	£21 0 0

Memorial Fund

By Interest on Investments (*less* Tax)	53 8 6
	£53 8 6

Medal Fund

By Interest on Investments (gross)	12 19 0
,, Balance of Expenditure over Income for year carried to Balance Sheet	4 13 6
	17 12 6

Endowment Fund.

By Interest on Investments (less Tax)	284 4 9
	£284 4 9

AERIAL SCIENCE, LIMITED

Balance Sheet,

	£ s. d.	£ s. d.
***Share Capital*—**		
***Authorised*—**		
20 Shares of 1/- each	1 0 0	
999 Shares of £1 each	999 0 0	
	1000 0 0	
***Issued*—**		
19 Shares of 1/- each		0 19 0
Sundry Creditors		551 11 9
Bank Overdraft		67 9 2
Subscriptions Received in Advance		153 6 0
Income and Expenditure Account—Balance at 31st December, 1933	1902 9 11	
***Less*—Deficit for the year to date**	265 16 11	
		1636 13 0
		£2409 18 11

We report to the Members that we have examined the above Balance Sheet with the Books are of the opinion that the Balance Sheet is properly drawn up so as to exhibit a true and correct information and the explanations given to us and as shown by the Books of the Society.

3, Frederick's Place, Old Jewry, London, E.C.2.

19th February, 1935.

Income and Expenditure Account

Dr.	£ s. d.
To Office Rent, Heating, Lighting and Insurance	570 19 4
,, Salaries	1003 6 10
,, Printing and Stationery	357 5 0
,, Postages, &c....	145 13 4
,, Office Expenses	469 17 4
,, Meetings	158 13 2
,, Dinners and Receptions	114 10 6
,, Journals and Pamphlets (*Less* Sales)	857 18 3
,, Library Expenses	109 19 1
,, Audit Fee	29 8 0
,, Prizes and Donations	41 0 0
,, School Lectures	22 2 5
,, Subscriptions Written off	87 19 0
,, Loss on Realisation of Investments	31 17 3
	£4000 9 6

(The Royal Aeronautical Society).

31st December, 1934.

	£	s.	d.
Office Furniture, Printed Books, Bindings, Old Prints, etc., at cost, as at 31st December, 1933	453	19	6
Stock of JOURNALS *and other Publications*	380	6	0
Stock of Stationery	13	0	0
Sundry Debtors, including Subscriptions owing	90	6	5
Investments at Cost—			
£1449 10s. 3d. 3% Conversion Loan, 1948/53 (Market Value as at 31st December, 1934, £1,532 16s. 11d).	1456	0	1
Cash in Hand	16	6	11
	£2409	18	11

of the Society, and have obtained all the information and explanations we have required. We view of the state of the Society's affairs as at 31st December, 1934, according to the best of our

(Signed) PRICE, WATERHOUSE & CO.

for the Year Ending 31st December, 1934.

Cr.	£	s.	d.	£	s.	d.
By Annual Subscriptions				3166	3	0
,, Interest on Investments (*Less Tax*)	38	13	9			
,, Income Tax Recovered	17	9	10			
				56	3	7
,, Donations				500	0	0
,, Examination Fees—*Less* Expenses				12	6	0
,, Balance of Expenditure over Income for year carried to Balance Sheet				265	16	11
				£4000	9	6

Finance

The Balance Sheets and Income and Expenditure Accounts of Aerial Science, Limited, and of Aeronautical Trusts, Limited, are published in this issue of the Journal. The form in which the accounts are drawn up shows, for Aerial Science, Limited, an excess of expenditure over income of £265 16s. 11d. as against an excess of income over expenditure for the year 1933 of £611 15s. 9d. This is a turnover of £877 12s. 8d., which is more than made up as follow:—

	£	s.	d.
Decrease in Donations	131	5	0
Interest on Investments (now credited to the Endowment Fund)	284	4	9
Writing down of stock of Journals and other publications	190	0	0
Loss on realisation of Investments (as against a profit in 1933)	326	13	11
Dinners and Receptions	133	5	9
	£1,065	9	5

The actual position, therefore, is more favourable than would appear from the way in which the accounts are drawn up. The policy of writing down the value of the stock of Journals each year is being continued until it will stand at a nominal sum, although the value of the stock is actually increasing each year. The transference of the Society's investments to the Endowment Fund has allowed a more accurate picture of the Society's position to be presented. The annual subscriptions again show a small increase which must be considered satisfactory. The accounts show that the Society is in a solvent position and is nearing the time when it will be able to balance its accounts independently of the generous donations it has had for so many years.

Trustee Funds

In 1933 there was put in hand the amalgamation of the various trust funds and prize funds which had been administered by the Society or Trustees. In 1934 these funds were all put under the control of Aeronautical Trusts, Limited. The Council appointed as Trustees:—

The President.
The Past-President.
The Honorary Treasurer (Major D. H. Kennedy).
The Solicitor (Mr. L. A. Wingfield).
Mr. Griffith Brewer.

The Council wish to place on record their thanks to all those who, in the past, have acted as Trustees and have given their time to the administration of the various funds. The Council also wish to thank the present Trustees who have now placed the various Trust Funds on a uniform basis for administration purposes and who have given their advice in the drafting of the deeds of the Trust Funds.

The formation of Aeronautical Trusts, Limited, will enable the Society to accept funds for the founding of prizes and awards in the future and ensures that they will be administered according to the wishes of the donors.

Solicitor

Mr. Lawrence A. Wingfield, M.C., D.F.C., A.R.Ae.S.I., has consented to act as Solicitor to the Society. During the year he has given his advice free on Committees and to the Council over various important matters concerned with

the Trust Deeds, and the Council wish particularly to thank him for the help and time he has so willingly given the Society in this way.

Honorary Treasurer

It is now eight years since Major D. H. Kennedy, F.R.Ae.S., accepted the position of Honorary Treasurer. They have been eight years of financial difficulty and upon Major Kennedy and the Finance Committee has fallen the onerous task of conserving the finances of the Society compatible with keeping it progressive. The Finance Committee meets regularly each month and discusses in detail all questions involving expenditure or investments of the Society's Funds. Major Kennedy has been an extremely active Chairman, and it is largely due to his untiring zeal on behalf of the Society that such financial progress has been made. The Council wish to place on record the deep debt which they owe the Honorary Treasurer for the help he has given the Society during the past eight years.

Honorary Accountant

The Honorary Accountant, Mr. Norman Smith, during 1934 completed his seventh year of office. As a member of the Finance Committee, Mr. Norman Smith's advice on the investments of the Society and matters affecting the accounting side of the Society has been most valuable, and the Council wish to record their thanks to him for the work he has done.

Secretary

This Report would not be complete without a tribute of thanks to our Secretary, Captain Pritchard, for all his work, advice, and energy in the interests of our body. This is no mere formal acknowledgment, but one of real thanks to one we look upon as almost the human embodiment of the Royal Aeronautical Society.

Staff

During the past seven years the work of the Society has increased very rapidly, without any corresponding increase in the staff. The staff of the Society, indeed, has always been one of the smallest of any corresponding Society. The Council feel that it is only due to put on record that it is due to their efficiency and their real interest in the work they are doing that the Society has been able to keep the administration expenses below those of similar societies.

CORRESPONDENCE

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

Dear Sir,

"THE TRAINING OF THE AERONAUTICAL ENGINEER."

Having been unable to attend either of the meetings at which the paper bearing the above title was discussed, I venture to ask that you will find room for the following comments. For the past 15 years it has been my job to teach the elements of aeronautical subjects to prospective aeronautical engineers, mostly undergraduates; latterly I have spent many hours (partly at the instance of your Council) in hearing the question of aeronautical education discussed from every angle and consequently I feel I have earned some right to an expression of opinion. On the major question discussed by Professor Pippard, namely, the time at which aeronautics may profitably be introduced, I desire emphatically to join those who already have challenged Professor Pippard's point of view.

Every teacher will agree with the lecturer's contention that an undergraduate course in engineering should deal essentially with fundamental principles. In developing these, however, and in order to bring them home to the average student, it has been found expedient to call in illustrations from actual practical work. A difficulty at once arises. The ramifications of the subject engineering are so great and the number of suitable illustrations so enormous that it has become customary to choose examples bearing on the particular branch which the student is likely to take up at the end of his college course. This method has abundant psychological justification and is also defended in many quarters on utilitarian grounds. At any rate, the natural consequence has been that engineering topics have arranged themselves in certain fairly well defined groups and courses of instruction and degree examinations now follow the same trend. The extent to which this partial specialisation has now developed is not always realised, particularly by the older generation. But glance at the following list of subjects set at the last London B.Sc. (Engineering) External examination, 1934—the largest of its kind in this country, and for which over 200 candidates entered:—Theory of Machines, Theory of Structures, Materials, Electrical Technology, Hydraulics, Aerodynamics, Surveying, Applied Thermodynamics, Electrical Machines, Electrical Power, Electrical Measurements, Telegraphy, Advanced Machines, Advanced Structures, Mathematics. Here there are 15 subjects in all, with two papers in each, so that a comprehensive knowledge is demanded in any subject, and of these the honours candidate is allowed credit for six only (the pass man five only). Other universities have similar schemes. For instance, in the Cambridge Mechanical Science Tripos in 1933 (the last that I have seen) the list of Group B (optional) subjects was as follows:—Theory of Structures (Civil), Theory of Structures (Mechanical), Aeronautics, Applied Mechanics, Electric Signalling, Electric Power, Heat Engines, Mechanics of Machines—of these the candidate for high honours took two or three. Of course, it may be argued that these examinations, and presumably those at all the other universities, need drastic revision, but all I wish to point out is that the young student (and his teacher) must be forgiven if he sometimes takes a glance at his final degree test and, further, that any practicable revision would not lead to a fundamentally different scheme. Whether we like it or no, every engineering undergraduate must be allowed, at least towards the end of his course, to concentrate his studies to some extent. I submit, therefore, that it is only rational that the prospective

aircraft engineer should be permitted to begin his acquaintance with the fundamental principles of what Professor Pippard calls the " specialised aeronautical subjects." In other words, aircraft engineering has every right to be ranged alongside the other branches, such as civil, mechanical, and the several sub-branches of electrical engineering. Professor Pippard's view is that the student would be better employed at this stage doing either the civil or mechanical course. If the latter, his subjects include, as two distinct matters (page 72, list *b*), Theory of Structures and Principles of Structural Design. What can the latter mean, as distinct from the former? Surely it can only imply work in steel and concrete and this, I suggest, is just the sort of thing that the budding aeronautical engineer does not want. Indeed, I think that Professor Pippard's argument *re* the electrical side might well be turned right round with the conclusion that the electrical man would have the less to unlearn if afterwards he takes up aeronautics.

One final word on the question of aerodynamics itself as a subject fit and proper for undergraduate study. I would remind Professor Pippard that the subject has developed primarily on an experimental basis, but further, the development, initiated by Rayleigh, has always been on strictly scientific lines, avoiding completely the mistakes made by an earlier generation concerned with the development of subjects such as hydraulics. It has been well said (I think first by Professor Bairstow) that aeronautical engineering is merely ordinary engineering plus refinement. If such be the case then all engineers should be trained as if they intended to enter the aircraft industry and no harm would be done if afterwards they adopted another branch!

Yours faithfully,

W. E. DUMBRILL.

Northampton Polytechnic Institute,
London, E.C.1,
15*th February*, 1935.

REVIEWS

Wings of Speed

By Sir Harry Brittain. Published by Hutchinson and Co., Ltd. Price 5/-.

Sir Harry Brittain is an adept at writing books for boys of all ages, for he manages to invest his stories of aeronautical adventure with that sort of glamour which is usually found in books dealing with the deeds of knights in armour. He has collected stories from all over the world, and we read of the adventures of flying doctors in Australia, of lost aeroplanes in the Sahara Desert, of flying under arctic conditions in Canada and of the troubles which afflict aeroplanes under the conditions of extreme cold and heat. We also read of the pioneer flights, such as that of Alcock and Brown across the Atlantic, and many others, including the first flights to South Africa and Australia, with an account of the adventures of the many record breaking pilots who have gradually reduced the flying time to these places.

The book is one which will be thoroughly enjoyed by those for whom it is written and will help them to appreciate the many difficulties which had to be overcome before the modern system of air routes could be initiated.

The Royal Air Force

By T. Stanhope Sprigg. Published by Sir Isaac Pitman and Sons, Ltd. Price 5/-.

This book describes the organisation of the Royal Air Force, discusses the duties which it carries out in peace time and in war, and contains a quantity of useful information about the prospects of those who enter it, either as officer or airman. Full details are given about methods of entry into all grades and in the case of such establishments as Cranwell details of cost are given, so that parents may be able to gauge their financial liabilities.

The book is a very useful one, especially in view of the increase in the Air Force now in progress, and those who are thinking of joining will be very well advised to obtain this book, where they will find the substance of numerous Air Ministry brochures explained in detail and arranged so that reference is easy. I suspect that many of those who are already in the Air Force will learn much about the Service from the perusal of this book and that the knowledge so gained will be of the utmost value to them in planning careers.

The 582nd Lecture delivered before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

A meeting of the Royal Aeronautical Society was held in the Lecture Theatre of the Royal Society of Arts, 18, John Street, Adelphi, London, W.C.2, on Thursday, November 15th, 1934, Lieut.-Colonel J. T. C. Moore-Brabazon (President) in the chair.

The PRESIDENT: Mr. Sikorsky was a name very familiar to the meeting, though perhaps his physiognomy was not; he had become an American citizen and lived on the other side of the Atlantic, so that we in this country did not see enough of him. His name, to the President at any rate, was associated always with giant machines, and he viewed aviation always from a big point of view. He was Vice-President and Chief Engineer of the Sikorsky Aviation Corporation, and his machines were used by that wonderful American Company, Pan-American Airways, which was perhaps not so conspicuous as some of the others because it did not operate up to New York, but in the south of North America. It was one of the few international companies, and was doing extraordinarily good work, thanks to Mr. Sikorsky's machines.

The problem of flying long distances overseas was essentially a problem which faced the British Empire. Consequently, of all types of aeroplanes, the big flying boat was the one which should interest them as much as, if not more than, any other. The S-42 was the largest amphibian in the world.

Mr. SIKORSKY: He appreciated the honour of being invited to address the Society on the subject of the large flying boat which had been constructed recently by his Company in America. He offered the explanation that, having chosen that subject, he did not intend to over-estimate the importance of the work, but simply to talk of his own experience. Whilst it may be best for a scientist to present general matters, the best thing that a practical engineer could do was to talk plainly about his own work, his troubles and difficulties, and to give facts and figures. That was why he had chosen for his paper, the recently constructed S-42.

The following paper was then read:—

THE DEVELOPMENT AND CHARACTERISTICS OF A LONG-RANGE FLYING BOAT (THE S-42)

BY

IGOR I. SIKORSKY

Almost a decade ago, with the rapid world-wide development of air transportation, came the demand for new types of aircraft. It became evident that a plane capable of operating from land or water was the logical step needed to open up larger areas for air transportation. The proximity of water compared with the remoteness of available landing fields to the centres of population was the deciding factor in amphibian development.

While the advantages of the amphibian are obvious, the limitations and difficulties of creating an efficient plane of this type are also evident. Compared to the seaplane or landplane, the amphibian must take care of the extra weight and parasitic resistance, as well as solve various other problems connected with combining the characteristics of the land and seaplane in one aeroplane.

In order to overcome these difficulties and produce an amphibian that would compare favourably in performance with the best land or seaplane, it was necessary to make the utmost effort to refine all basic elements. In other words, it was necessary to create highly efficient power plant, wing and control surface units so that a wide margin of increased performance would be obtained that would compensate for the extra weight and resistance of the amphibian.

Evolved from painstaking study and research came the S-38. Its history is the conception of the Pan-American Airways, the air yacht of the private owner, and the pioneering craft of exploration into hitherto inaccessible regions of Central and South America and Africa. Over a five-year period more than 100 of these aircraft were delivered and the majority of them are still in service.

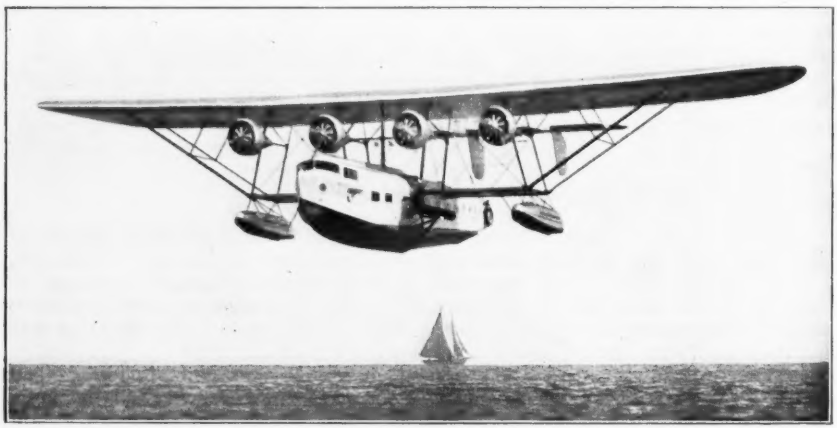
As the characteristics of this aircraft became more and more evident, the hazy dream of large aeroplanes materialised into a definite plan. With the increasing business of the Pan-American Airways, their fleet of S-38's became inadequate. Upon their request, the big flying boat idea became a reality.

The three Clipper flying boats that now fly over the Southern Americas are the results. In our minds, at the time of designing, was a flying boat diverting in outline from the usual Sikorsky outrigger design, but it was felt that radical changes were not advisable, particularly because the large plane was to be an amphibian. Knowing what the S-38 could do, it was felt that a large size edition of this type would be the logical jump from an eight to a forty-passenger ship.

A considerable amount of work, research study and experimentation was spent in the development of the S-40. The theoretical work, design, stress analysis and research required the full time of the Sikorsky organisation for more than two years. The Sikorsky Company realised that upon the experience that this model would give, an even more efficient amphibian would be based. Even then this new amphibian was gathering shape in the minds of the Sikorsky designers.

From its first flight, the S-40 was a success. Capable of carrying forty passengers over a considerable range, the S-40's dove-tailed with the need of larger equipment to meet an ever-increasing passenger list.

The engineers who built the S-40 watched the performance very closely. In November, 1931, when the first " Flying Clipper " made its cruise from Miami to Colombia and the Panama Canal Zone and return, the designer was



American Clipper S-40.

on board and had several conferences with Colonel Charles A. Lindbergh, technical adviser to the Pan-American Airways and chief pilot in charge of this flight, wherein the basic ideas and main requirements for a new type large flying boat were set down.

Immediately afterwards the engineers of the Sikorsky Company started actual research and development of a seaplane along these lines. The endeavour was to obtain a much higher all-round efficiency that would permit a much greater flying range and higher cruising speed, as well as to introduce various other improvements and refinements.

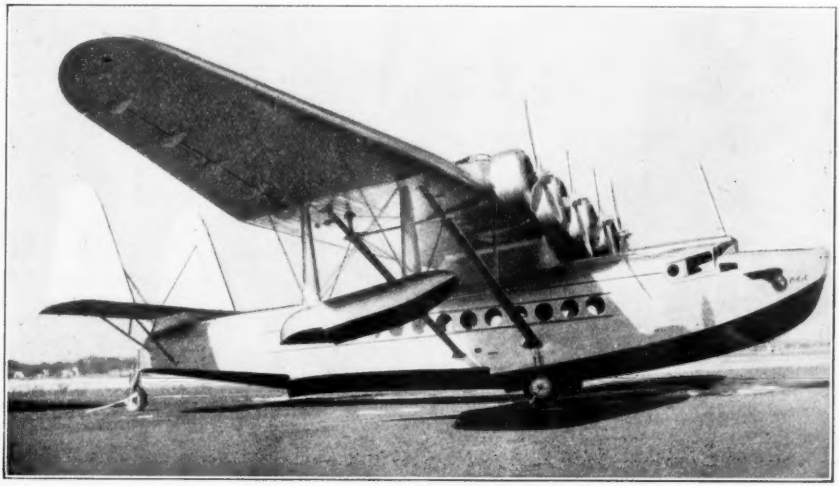
In the meantime, Pan-American Airways had placed in extensive service the second and third Clipper aircraft. The experience obtained from millions of miles of commercial flying gave Pan-American Airways excellent data for the development of a very complete set of detailed specifications for a plane that would cover the needs of further expansion and the possibilities of a commercial line across the Atlantic. Written into the specifications were requirements that were seemingly far in advance of the progress of aviation.

Gathering impetus from the reality of the S-42, power plant development advanced with great rapidity, so that when the question of engines and propellers became imminent, the Pratt and Whitney Aircraft Corporation was ready with its greatly improved Hornet model, and Hamilton Standard Propeller Company had to offer, what was considered by the Collier Trophy Committee an outstanding advance in the aviation world, a practical controllable pitch propeller.

Knowing the difficulties that are encountered in the endeavour to coincide the desired with the practical, close co-operation between the Pan-American Airways and the Sikorsky Company was necessary. Every detail from design to final fabrication was an approval based on careful criticism and study; every phase that forms a part of the commercial airline was considered, including cost of operation, maintenance, durability, and passenger comfort.

Design work again required over two years. Reports, records and tests, in seemingly endless procession, were culled of their best ideas and these were incorporated as far as was practical.

Stress men spent tireless hours figuring structural strength that would meet high self-imposed safety factors and still allow for simplified construction and



Side view—the S-42.

low weight. Their complete analysis covers almost a thousand pages of closely typed matter with no consideration to the countless pages that contributed to the final figures.

Because of the stringent requirements of the contract calling for a useful load to gross weight ratio of 47-53, a rigid weight control was set up. A three-fold system was employed—one, an estimation from the design figures allocating to each unit a certain share of weight; another calling for calculation from the finished drawings and a comparison with the estimated; and the third, a programme of actual weighing of parts. The value of this triple control is shown in the 48-52 ratio obtained.

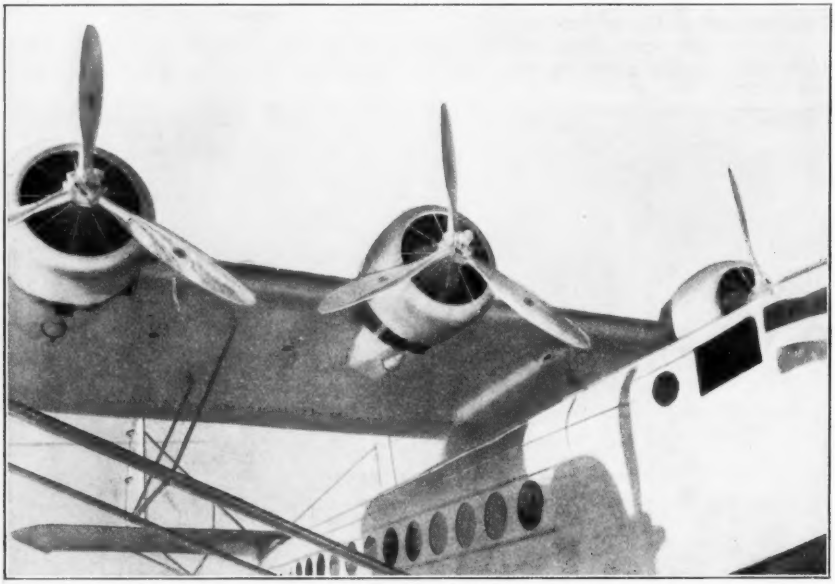
No drawing was approved until it passed through the manufacturing department for a check against complicated design that would involve expensive fabrication or that would require undue maintenance when put into operation.

The S-42

In its very outline the S-42 represents simplicity. Diverting sharply from the past Sikorsky designs, external bracings have been reduced to a minimum. The tail, instead of being supported by outriggers, is attached directly to the hull.

The one-piece wing with tapering tips is attached to the hull by means of a superstructure. The necessary large external struts brace from the hull to the outer portion of the wing. These struts are the largest streamlined duralumin sections ever extruded.

With a span of 114ft. 2in., the wing has an area of 1,330 square ft. Spars and compression members, of modified Warren Truss design, are constructed of extruded duralumin shapes. Stressed metal skin covers the major portion of the wing surface. Flush type rivets are used throughout the external surface.



Power—the S-42.

Extending along the full straight portion of the rear spar is the hydraulically controlled flap. The flap is mechanically operated by means of a substantial hydraulic piston. The piston is actuated by an electrical pump that is controlled from the pilot's compartment. For emergency use a manually operated pump is provided. The angular position of the flap can be altered in accordance with the attitude of flight, thus changing the performance of the whole wing.

Ailerons of conventional design, tapering in conformity with the wing plan, are hinged to the rear spar outboard of the flaps.

The power plant units, consisting of four Pratt and Whitney 700 h.p. geared Hornet engines, together with the necessary accessories, are attached to the front spar by means of welded steel tubular nacelles. Completing these units are the three-bladed variable pitch propellers, the largest of this type ever produced by the Hamilton Standard Propeller Company.

The full anti-drag rings and nacelle cowls merge into the wing at the front spar.

Recessed into the leading edge are powerful landing lights. The lenses of these lights follow the curvature and form part of the leading edge.

Eight sections of the leading edge, one on either side of each engine, fold down and form engine servicing platforms.

Along the interior of the leading edge run the control cables, electrical conduits and other control and fuel units. All installations are made suitable for easy inspection and maintenance.

Cradled between the spars and compression members are eight elliptical fuel tanks of a total capacity of 1,240 gallons and four similar shaped oil tanks of 74 gallons capacity. Holding these in place are metal straps which are covered with thick padding to insure vibration insulation.

Removable panels, above the fuel and oil tanks, and on the entire centre of the lower surface afford access for inspection and servicing.

The re-fuelling system in the centre portion of the wing is an interesting time-saving device. A single intake pipe directs fuel under pressure to any one or all tanks by means of a series of control valves.

Equal in importance with the wing are the parts that make up the body group.

The two-step, long stern type hull measures 67ft. 8in. from bow to stern.

Deep keel, transverse frames which are widely spaced in order to facilitate maintenance, and heavy stringers form the hull skeleton. Keel and frames are of plate girder type. Duralumin shapes and sheeting are used throughout.

Take-off—the S-42.

The skin covering has the appearance of a smooth unbroken surface. This has been obtained by the use of a filler in the skin seams and the impressions of the slightly indented flush type rivets.

Nine watertight doors separate the various compartments.

Marine equipment is located in the bow compartment. This compartment has been designed especially large to afford easy handling of a convenient anchor winch and to facilitate rapid mooring operations.

The pilot's compartment following averages eight feet wide and seven feet from bulkhead to bulkhead.

An aisle 20 inches wide separates the pilot and co-pilot seats. These seats are extra roomy and are adjustable. They are designed to supply the maximum of comfort for long flights.

Both pilots have an unobstructed view of the complete flight instrument board. Special requirements as to making all instruments and parts readily removable for checking and servicing have been rigidly adhered to.

To the rear of the pilot's seat is located the flight mechanic's quarters. From his position the mechanic can readily attend to all the details under his control. Grouped on a separate panel directly in front of the mechanic's seat are all the instruments pertaining to power plant operation.

Opposite the mechanic's quarters and in an uncrowded space is the radio receiving and sending station.

Surface controls are of the dual type featuring ease of operation. Controls are hooked up to the automatic pilot unit located beneath the floor. Dials and instruments for setting and regulating the automatic pilot are on the centre of the flight instrument board within easy reach of either pilot.

Engine control units are centred overhead, comfortably reached by either pilot and the mechanic. It affords either unit control for all engines, or selective control for each engine.

Next to this unit are the engine fire extinguisher controls. A twist of a dial directs extinguishing gas to one or all engines.

Reached from the outside by a hatch large enough to accommodate large packages as well as permitting for passenger exit, and located between the pilot's compartment and passenger cabins is the front baggage compartment. The allowable baggage space is 157 cubic feet. Here are also stored two life rafts and various tools. A strong box for valuables is located under the floor.

At the main passenger stairway in the rear are located additional baggage compartments with a total capacity of 95 cubic feet. Large packages find ready access through the main passenger entrance that measures 25 inches by 72 inches.

Between the front and rear baggage compartments are located the passenger cabins and the lavatories.

The four passenger cabins, measuring 76 inches by 110 inches each, seat eight passengers. More than sufficient space is allowed for wide aisles and comfortable leg room. The distance from the floor to the ceiling is well over six feet.

Tubular racks suspended from the bulkheads support the seats. This construction eliminates chair legs, thus permitting an unobstructed space beneath each seat for luggage.

Seats are adjustable to meet individual comfort. High head rests afford complete relaxation.

Accessories, including carpets, removable tables, magazine racks, and curtains, harmonise with the decorative scheme.

Sound and vibration have been the subjects of careful study. Thick pads of soundproofing material fill in the space behind the walls and ceiling. Because of their vibration, springs have been replaced in cushions by a special material that is proving more serviceable and comfortable. Windows are held in place by a clincher type rubber ring without the need of fasteners that would cause

shattering. In any passenger cabin conversation may be carried on in a normal tone.

A concealed ventilating system supplies upwards of 30 cubic feet of air per passenger per minute. Auxiliary to this is an efficient exhaust system.

Installation fittings on walls, ceiling, floors, and seats are such that an entire passenger cabin can be stripped to its bare structure within 40 to 50 minutes and reinstalled in a similar period.

Each cabin is equipped with safety belts and lifebelts are distributed throughout the boat; in convenient locations are fire and emergency equipment. The two life rafts in the front baggage compartment and the two located rearward of the main stairway are suitable for carrying a full capacity crew and passenger list.

The superstructure, already mentioned, also serves as a passage-way for items of controls that pass from hull to wing. Entrance is afforded to this structure from the inside of the cabin as well as from the outside. The internal space of this structure is such as to allow a man to work with comfort.

Every external part of the hull may be reached by a centre ridge walk-way that extends from bow to stern. This walk-way, together with the wing walkways and the engine platforms, makes it possible to conduct almost any inspection or servicing operation without the need of outside scaffolding. The economic feature of this is obvious.

Pontoons, hinged from the wing on two streamline struts and braced by cross wires, follow similar construction design as the hull.

Easy handling from sea to land, or *vice versa*, is offered by the beaching gear. This is a three-part unit consisting of two twin-wheels-on-a-strut car-

Comfort—typical Sikorsky interior.

riages that attach to special fittings on the front of the hull and a single tail wheel that fits into a socket at the stern of the hull. All carriages may be turned on their axes so that motion is possible in any direction. Seven to ten minutes is required to attach or detach the entire gear.

Even more important than the structural characteristics of the S-42 is its performance.

Reports on performances were handed in by three of the outstanding pilots in the aviation world—Captain Boris Sergievsky, holder of numerous world records and chief test pilot for the Sikorsky Aviation Corporation; Mr. Edwin Musick, chief pilot for the Pan-American Airways, and an airman of outstanding experience and ability; and the final stamp of approval by Colonel Charles A. Lindbergh. Thirty-two flights on an average of over two hours each filled in the five months' period of performance testing.

The final accepted report shows the performance as:—

Gross weight	38,000lbs.
Full speed at 5,000ft. altitude	188 m.p.h.
Full speed at sea level	180 m.p.h.
Speed at 75 per cent. b.h.p. at sea level	160 m.p.h.
Speed at 70 per cent. b.h.p. at 12,000ft. altitude...	170 m.p.h.
Climb, initial, four engines	1,000 f.p.m.
Climb, initial, three engines	400 f.p.m.
Ceiling, service, three engines	7,500ft.
Full speed at sea level, three engines	157 m.p.h.
Speed at 75 per cent. b.h.p., sea level, three engines	135 m.p.h.
Stalling speed	65 m.p.h.
Time of take-off, dead calm	25-30 sec.
Ceiling, service, four engines	16,000ft.
Range at cruising speed, sea level	1,200 miles
Range with pay load of 1,500lbs. (cruising speed 145 m.p.h. at 6,000ft. altitude)	3,000 miles

During the test flights the following world records for Class C-2 seaplanes were established:—

For a distance of 1,000 *km.* (621.4 *mi.*).

Speed	253.7 km./hr. (157.7 mi./hr.).
Speed with 500 kg. (1,102.3lbs.) ...	253.7 km./hr. (157.7 mi./hr.).
Speed with 1,000 kg. (2,204.6lbs.) ...	253.7 km./hr. (157.7 mi./hr.).
Speed with 2,000 kg. (4,409.2lbs.) ...	253.7 km./hr. (157.7 mi./hr.).

For a distance of 2,000 *km.* (1,248.8 *mi.*).

Speed	253.4 km./hr. (157.5 mi./hr.).
Speed with 500 kg. (1,102.3lbs.) ...	253.4 km./hr. (157.5 mi./hr.).
Speed with 1,000 kg. (2,204.6lbs.) ...	253.4 km./hr. (157.5 mi./hr.).
Speed with 2,000 kg. (4,409.2lbs.) ...	253.4 km./hr. (157.5 mi./hr.).
Greatest load to 2,000 m. (6,561.6ft.) ...	7,533 kg. (16,608lbs.).
Altitude with 5,000 kg. (11,023lbs.) ...	6,203.6 m. (20,406.7ft.).

Operating Efficiency

In no way, however, has high performance reduced the practical purposes of this boat. The weight ratio of useful load to gross weight is very satisfactory. With a weight empty of 19,764lbs. and a licensed gross weight of 38,000lbs., a useful load of 18,236lbs. is obtained. This ratio is then in the nature of 48:52, or the useful load equals 48 per cent. of the gross weight.

The weight allocations for a gross weight of 38,000lbs. and a range of 1,200 miles fit commercial requirements. The fuel and oil for this range weigh 7,995lbs.; equipment weighs 2,181lbs., and pay load equals 7,060lbs. Should consideration be given to using the S-42 for fast freight only, practically all the 2,181lbs. of equipment, plus the chairs, wall and ceiling trim and sound-proofing, can be dispensed with, giving a pay load of approximately 10,000lbs. over a range of 1,200 miles. For a range of 3,000 miles, cruising at 145 miles per hour and at 6,000 feet altitude, the allowable pay load will be 1,500lbs. Thus the S-42, keeping well within the safe limitations of structural strength, capable of maintaining a high ceiling with only three motors, and at the same time carrying a reasonable pay load, is entirely suitable for the establishment of trans-oceanic routes.

The following table indicates the benefits of the S-42 as compared to the S-40:—

	S-40.	S-42.
Weight empty	21,000lbs.	19,764lbs.
Gross weight	34,000lbs.	38,000lbs.
Equipment	1,000lbs.	2,181lbs.
Crew	1,000lbs.	1,000lbs.
Gas and oil (1,000 miles)	7,800lbs.	6,692lbs.
Pay load	3,200lbs.	8,363lbs.
Cruising speed (1,000ft.), m.p.h.	115	157
High speed, m.p.h.	137	182
Horse-power	2,300	2,800
Fuel consumption (cruising, per hr.) ...	140 gals.	162 gals.
Landing speed, m.p.h.	65	65
Range, miles	1,000	1,000
Time	8.7 hrs.	6.37 hrs.
Wing loading	19.5	28.58

Here is an indicated increase in the S-42 of 5,163lbs. pay load over the S-40.

If equal pay loads are considered, that is, 7,500lbs., the range for the S-40 is 479 miles and in the S-42 is 1,130 miles, an increase of 651 miles.

The extensive test made with the S-42 made it possible to make some interesting comparative measurements. With the engines of the S-42 throttled down to 575 b.h.p. to conform with the b.h.p. of the S-40's Hornet " B " engines, the speed obtained was 163 m.p.h. as against 137 m.p.h. obtained from the S-40.

The improvement in efficiency of the S-42 is better exemplified if a study is made of the cruising speed of the S-42 against the S-40, using equal horse-power in each case. Using 432 b.h.p. per motor, the S-40 cruises at 115 m.p.h., while with the same power and an increased gross weight of 4,000lbs. the S-42 cruises at 145 m.p.h., an increase of 30 m.p.h.

From an economic viewpoint, that is, comparing load carried against fuel consumed, an important deviation is found. Each plane using the same horse-power and the fuel consumption per hour of the S-42 being 144 gallons, and that of the S-40 140 gallons, the following ton-mile gallon is given:—

	Miles per gallon.	Payload in tons (1000 miles).	Ton mile per gallon.
S-40	0.82	3300/2000=1.65	1.35
S-42	1.0	8505/2000=4.25	4.25

In view of the fact that operating and maintenance costs are based on flying hours, consideration is here given to that item. Equal in size, the S-40 is again taken for our analysis. The unit of maintenance and operating costs per hour being considered equal, we find that for each flying hour the S-40 is credited with (1.65 tons x 115 mi.) 169.75 ton-miles, and the S-42 (4.25 tons x 145 mi.) 616.25 ton-miles.

It is quite clear that in this consideration of pay load ton-miles that operation and maintenance cost vis-a-vis load carried would be decreased in the same proportion. In reality, the decrease will be substantially greater because of the refinement for fast and simplified inspection, servicing, and maintenance incorporated by the Sikorsky engineers in conjunction with the staff of the Pan-American Airways.

General Considerations

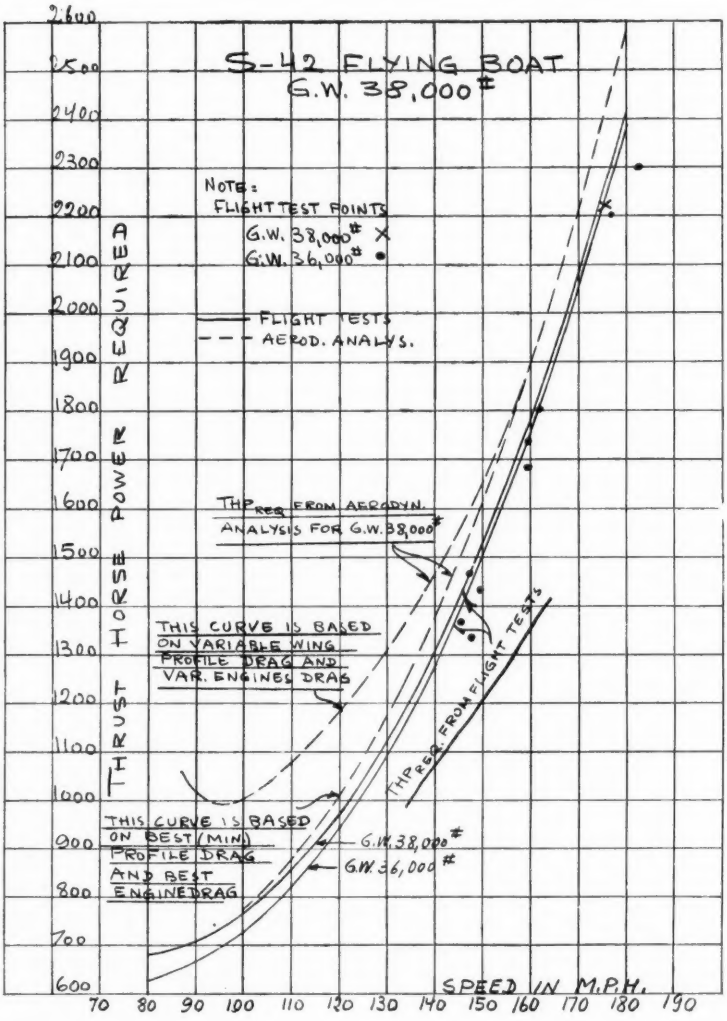
Because of the general cleanliness of the S-42, due to the careful study of the aerodynamic interference of parts, the total parasite resistance at cruising speed of 160 m.p.h. is only 3,620lbs. At the time of designing, careful consideration was given to the cantilever wing, but it was felt that the increase in profile resistance, due to the greater thickness of the centre section of the wing, would be greater than the drag of external struts. Research also revealed that the structural weight of the cantilever wing would be greater than the present wing and struts.

The table attached gives the curves of the original estimated performance compared with data measured during test flights. It should be noted that actual performance is in general accord with the figures estimated by the more liberal simplified method in which the profile drag of the wing and the resistance of engines are taken as having a constant value subject to the square of speed. It is believed that the slight excess of actual performance over the original estimate is due partly to greater scale speed effect other than the one that was considered, and partly due to the smooth surface created by flush riveting. It is evident that the ship with full load is able to maintain flight easily, using much less than half the power available. It is shown further that the best L/D ratio of the whole aeroplane is above thirteen. The data on which the table is based were recorded during test flights with calibrated intake manifold pressure gauges mounted on all engines. The reading of these instruments, plus careful observation of the r.p.m., permitted the accurate establishment of the power used at various conditions of speed and load.

After a careful study of the conditions under which this ship would operate, it was decided to have a high wing loading. The ship was designed primarily for high cruising speed and operation over long trans-oceanic routes. A service of this character offers no intermediate landing possibilities, and in view of the distances and duration of flight, the ship must be able to withstand varying weather conditions. Good airworthiness in stormy weather was considered most essential. A simple aerodynamic study shows that the action of a squall or of a vertical air gust becomes more violent as the wing loading decreases. Therefore, a heavy wing loading of 28.5lbs., combined with ample h.p. per square foot of 2.1 b.h.p., was found desirable.

Flight tests confirmed this decision. The S-42 flies easily and smoothly in the roughest of weather. The comparatively small and rigid wing has the added advantage of safely weathering strong wind and heavy squalls while afloat, particularly with the flap in neutral position. Added approval of this consideration is given by nature. It is interesting to note that large birds that fly over the sea, having long distances to traverse before being able to alight in case of stormy weather, have a much heavier wing loading than birds of similar size that fly over land.

The disadvantages of heavy wing loading, namely, difficult take-off and fast landing, were avoided by the use of the specially designed flap. After a very careful wind tunnel study of several types of auxiliary surfaces, preference was given to the straight flap that now fills up the rear of the wing between the ailerons.



This flap produces an increase in lift of about 40 per cent. When placed at a 40 degree angle, the flap affords an actual stalling and landing speed of 65 m.p.h.

Test showed that the best position for take-off is with the flap set at $+10°$ to $+12°$. Carrying a definite test load, the ship with the flap in neutral position took 12 seconds for take-off. Landing immediately, the flap was set at $+10°$ and the take-off time was reduced from 12 seconds to 7 seconds, indicating that the flap decreased take-off time by nearly 40 per cent.

Future Considerations

The results achieved with this new seaplane are encouraging for the future development of large planes. They prove that it is now possible to make accurate

estimations of structural weights, performances and all general characteristics for planes of even more substantial size and advanced design. It is, therefore, permissible to make a forecast of the future development, design and operation of large aircraft.

In the past it has been intimated that efficient planes of large size would be impractical. It was argued that with increasing size the structural weight would increase beyond reasonable proportion to the gross weight, so that the ratio of useful load to gross weight would become progressively worse. It is claimed, however, that if careful study is made to distribute the power plant weight and other units of weight along the wing, stresses decrease and an efficient structure becomes possible.

As previously mentioned, the structural weight of the S-42 is only 52 per cent. of the gross weight; but, at the same time, the ship is built not only in strict conformity with the load factors as set down by the U.S. Government, but, in many cases, has even wider margins of safety.

In view of these considerations, it is reasonable to conclude that efficient planes of still larger size and weighing hundreds of tons are not only possible but practical.

With respect to structural limitations, the hydro and aerodynamic advantages of large planes, particularly flying boats, may be pointed out. As the size of the boat hull increases, the displacement and therefore the normal loading grows as the cube of the linear dimensions, while the air resistance increases substantially less than the square. This is due to the scale effect and because many auxiliary parts, such as pilot windows, doors, handles and many other items, do not increase in proportion to the size. In line with this, the water characteristics improve as the size increases, and high aerodynamic efficiency, offering high cruising speed, becomes entirely possible for the large seaplane.

Passenger comforts would increase with the size of the ship. In a seaplane of 100,000lbs., or more, it would be possible to have individual cabins, dining-rooms, smoking lounges, etc., entirely comparable in comfort and luxury to those of the modern ocean liner.

There is no doubt that planes of great weight, capable of non-stop ocean flights, cruising between 150 to 200 miles per hour, can be designed at this time and be ready for service within two and a half to three years.

Greater cruising speeds are possible, but the size of the earth does not warrant greater speeds.

The progress of air transportation will benefit more if designers will give more attention to increased passenger comfort and ways and means to lower transportation costs rather than greater speed. It is expected that within the next five years great strides will be made in this direction.

How high will the luxury air liner of the future fly? A few years ago nearly everyone pointed to the stratosphere as the height. While this is possible, the writer believes that the contingent limitations and difficulties will permanently keep the major part of air traffic below the stratosphere.

The need of an airtight plane for stratosphere flying brings up a very serious consideration. Should a leak occur, allowing a momentary release of the oxygen in the ship, disaster would result. Possible safeguards against this condition would mean large increases in structural weight.

This consideration, together with the well-known basic complications of the stratosphere plane, will probably limit its use to a few exceptional services.

The flying altitude of the commercial air liner will be between 12,000 to 20,000 feet. At this altitude the plane will be clear of the majority of air disturbances and will be capable of cruising at considerable speed.

This discussion is based on the results of present-day achievements. Projected from them will be the future great air liner. Present aerodynamic experience predicts aircraft of long ranges, carrying many passengers with comfort, safety and dispatch over routes that will reach to the far corners of the world.

Discussion

Mr. H. O. Short (Fellow): They were indebted to Mr. Sikorsky for having made a long journey from America to give the Society his interesting account of his practical achievements in flying boat construction.

He did not think that any foreign designer of aircraft would wish to deny the share of credit which fell to British flying boat constructors in regard to flying boat development, especially where all-metal construction was concerned. It could not be denied also, however, that they in this country lagged behind where very high cruising speed was concerned.

He believed the cause of their having fallen behind in the matter of speed was that they had not made speed the first consideration to which other desirable features of air travel might be subordinated. When they had really endeavoured to achieve speed, as they had in connection with the contest for the Schneider Trophy, they had shown what they could do against the leading aircraft designers of the world; also, Messrs. De Havilland had shown what they could do when they had made up their minds to be first in Melbourne recently. They in this country designed their machines around a set specification which defined comfort, equipment, stalling speed, ease of maintenance, etc.; the speed was what it might be, but the specification was immutable. On the other hand, it would appear that the American designers had specifications which fixed the speed as the main consideration, and that other considerations were fitted inside that. Perhaps some of the more technically minded might care to say something about high wing loading; that was a matter in which they in this country had been afraid to make explorations. Risk in aircraft development involved expenditure and possible losses; success or failure involved the national prestige, and that was a matter which should concern the Government of a nation.

Mr. W. O. Manning (Fellow): In order to illustrate the advance in design made by Mr. Sikorsky, he compared the performance of the S-42 with the flying boat used by Imperial Airways, Ltd., in the Mediterranean, though he pointed out that his remarks were not intended as a criticism of the latter. It was sufficient to say that when it was introduced its performance was certainly better than that of any other machine of its type in the world. But Mr. Sikorsky had put it completely out-of-date.

In spite of the fact that the S-42 had rather less horse-power in proportion to its weight, its cruising speed was 52 m.p.h. faster than that of the English boat; the speed of the S-42 with one of its engines stopped was 20 m.p.h. faster than that of the English boat with all engines operating at full power. The S-42 carried nearly 1,000lbs. more pay load in addition to fuel for 550 miles increased range. The climb of the S-42 was also better, the landing speed was 5 m.p.h. higher, and the time to leave the water was about the same. This improvement in performance could only be described as colossal. The new Atlantic liner, "Queen Mary," possessed hardly so great an advantage over the so-called Atlantic greyhounds of the last century as the S-42 possessed over the English flying boat referred to.

In order to illustrate the matter still further, Mr. Manning roughed out a specification for a new flying boat of the size and power of the Imperial Airways boat, based on what Mr. Sikorsky had proved to be possible. The figures for the proposed boat and the present Imperial Airways boat were as follows:—

	Proposed Boat.	Imperial Airways Boat.
Total weight ...	32,000lbs.	32,000lbs.
Horse-power ...	2,400	2,400
Range	450 miles	450 miles
Crew	660lbs.	660lbs.
Equipment	1,560lbs.	1,560lbs.
Weight empty ...	16,600lbs.	18,900lbs.
Fuel	2,120lbs.	3,420lbs.
Pay load	11,060lbs.	7,460lbs.
Top speed	200 m.p.h.	137 m.p.h.
Cruising speed ...	170 m.p.h.	105 m.p.h.
Landing speed ...	65 m.p.h.	60 m.p.h.
Initial climb ...	1,000 ft.p.m.	840 ft.p.m.
Time to take-off ...	25-30 secs.	25-30 secs.

Thus, said Mr. Manning, there would be a saving of 2,300lbs. in weight (empty) of the new boat as compared with the older one. There would be a reduction of about one-third in the weight of fuel for the range of 450 miles, owing to increased speed; the pay load would be increased by about 3,500lbs., partly owing to the reduction of the weight of the machine empty and partly owing to the saving of fuel. He had adopted the top speed of 200 m.p.h. for the proposed boat, because such a boat could not be produced until about two years hence, and by that time one would naturally expect an improved performance over that of Mr. Sikorsky's S-42, which was designed two or three years ago. The cruising speed of the proposed boat would be 65 m.p.h. faster than that of the Imperial Airways boat; the landing speeds would be much the same, and the initial climb, which was not a very important item, would be increased by about 160ft. per minute in the case of the proposed boat.

Major R. E. PENNY (Associate Fellow): The secret of the success of Mr. Sikorsky's flying boat was to be found in the enormous amount of detail work, the fairing up of the details so that the combined resistances had been reduced to an absolute minimum.

He would like a little further information concerning a few of the figures, relating to stalling speed and times of take-off, because the facts were not quite clear to him.

Mr. Sikorsky had displayed wisdom and foresight in concentrating upon large flying boats, and one was grateful to him for having stressed the cumulative aerodynamic and hydrodynamic advantages of the flying boat in increasing sizes. The theory of this was well known, but it was dismissed by most people without a moment's thought or it passed out of mind for other considerations, which considerations were of minor importance if one took the long view as Mr. Sikorsky had. It must be the conviction of everyone with imagination that a trans-oceanic service by air could be practicable only if large flying boats were used. Not only did Mr. Sikorsky share this conviction, but he had acted upon it. That was why they would have the pleasure, about four years thence, of congratulating him upon the production of a flying boat suitable for a trans-Atlantic service affording efficiency and comfort far in advance of anything produced in Europe.

Mr. A. GOUGE (Fellow): They in England had to take a lesson from the paper and re-cast their ideas, with particular reference to the wing loading. It would appear that practically the whole of the improvement in this boat over its predecessors was due to the increased wing loading and aerodynamic cleanliness. In England they had been very loath to work to such high wing loadings because of their effect upon the landing speed. Whilst he gathered that the landing speed of the S-42 was 65 m.p.h.—which, incidentally, required a lift coefficient of nearly 1.4—it seemed to him that the question of the landing speed on the water, if the water were reasonably calm, was of minor importance.

Would Mr. Sikorsky amplify his figures to show what would be the weight of the aircraft when the range was 3,000 miles, which range was referred to at the bottom of the table showing the performance of the S-42? From a rough addition, it appeared that the weight of the aircraft under this condition was 40,000lbs., instead of the 38,000 mentioned at the top of the table as being the gross weight. He also asked for the benefit of Mr. Sikorsky's experience of the long struts running to the hull—whether they got in the way when loading the aircraft and whether they were subject to much corrosion and damage. It had been the practice in England during the last year or so to delete struts of this nature, owing to the amount of trouble attributed to them in the direction of corrosion and damage.

With regard to possible future developments, he agreed that as the size of the boat hull increased the cross-sectional area was again up less than the square of the linear dimensions and, therefore, the air resistance was relatively improving for this reason, so that a larger boat should perform better than a small one.

Mr. M. LANGLEY (Member): It was a little difficult to make comparisons between the S-42 and others, on economic grounds, which must include petrol consumption against pay load, or resistance. Would the tankage mentioned in the paper represent United States gallons or imperial gallons? The difference between the two was quite considerable.

One outstanding figure was that of the ratio of the gross weight to the tare weight, which was far above that for any machine produced in this country, within his knowledge, particularly in flying boats. Flying boats had always been regarded as inefficient in comparison with land planes, only to be used when land planes were not possible; indeed, land planes had been used frequently on services which were essentially flying boat routes. It appeared, however, that the S-42 was not only ahead of all other flying boats, but that economically, and from a profit-earning point of view, in spite of its speed, it was better than any commercial land plane in this country.

At every turn one heard the argument that speed was obtained only at the expense of greater horse-power; Mr. Sikorsky had shown, however, not only by his ideas but by his products, the existence of which could not be denied, that increased speed could be obtained by other means than by increasing the horse-power. They had known that in theory, but he had shown it to be possible in practice, and the great lesson to be learned from his paper was that more courage and more forethought was needed.

Mr. S. SCOTT-HALL (Associate Fellow): Referring to the author's comparison between the S-40 and S-42, he gathered that the figures given for the S-40 were those for the aircraft as a flying boat, not an amphibian. The photographs had shown it with amphibian gear fitted.

Did Mr. Sikorsky consider any radical improvements in flying boat hull design could be expected—not merely minor improvements, such as cleaning up the surface of the hull by such expedients as flush riveting, but by radical changes in design?

He had examined some figures for the landing speed of British flying boats, and, indeed, had made exactly the same comparison that Mr. Manning had just given, but had decided that it was so pessimistic that he would not pursue it further. But it was interesting to note that Mr. Sikorsky's S-40 had a wing loading of 19½lb. per sq. ft. and yet its landing speed was given as 65 m.p.h. The lift coefficient, worked out on those figures, was in the neighbourhood of 0.9. What was the wing section used on that machine and were there flaps of any description? The above figure seemed extremely high. Moreover, the machine was a high wing monoplane and one would not expect much " ground effect."

On this question of landing speed, which was one of the main factors that had influenced British design, they had been rather inclined during the last few

months to condemn themselves unnecessarily. In days gone by—as of course now—the main consideration was to produce a machine that was safe. Engine reliability was not then what it is to-day, and landing speed was a factor far more prominent in people's minds in connection with safety than it had been recently. They should not forget the low-speed research carried out in this country at a time when the question of safety had been translated in terms of landing speed. It had placed them in the forefront as regards safety in aviation. Low landing speed was one of the main factors influencing top speed and now that engine reliability had eliminated its necessity, they had been left so to speak in the lurch.

Commenting on Mr. Sikorsky's reference to the heavy wing loading of sea birds, he presumed that the lecturer had in mind the albatross. He pointed out that that bird had not got it all its own way, because under certain conditions its take-off was a matter of concern both to the bird itself and to anybody watching it; and from that fact they could learn a lesson which would perhaps modify Mr. Sikorsky's remarks in that connection. But in spite of this it seemed that they had reached a point at which they could no longer disregard the demands of top speed; the fetish of low landing speed was imposing a burden on British aviation which it could not support.

Mr. E. M. Buxton: The two extreme conditions mentioned by Mr. Sikorsky when discussing landing speeds did not cover the whole of the variations, and one would like to know how his flying boat hull would behave under conditions in which there was not a great deal of wind but a long swell.

It was most entertaining to hear a lecture delivered from a severely practical point of view, leading to conclusions which people of less experience than the lecturer might consider to be visionary.

Mr. E. C. Gordon England (Fellow): The conclusion at which Mr. Sikorsky had arrived, that neither he nor his engineers knew anything about aerodynamics, impressed him. They might learn a tremendous lot from a statement to that effect, made so charmingly and modestly, because it contained an enormous amount of truth. The trouble was that they *thought* they knew a great amount about aviation whereas they were virtually ignorant—and Mr. Gordon England emphasised that he made that statement in all seriousness. He felt sure that Mr. Sikorsky appreciated fully the truth underlying it. They imagined that they had established the main facts about aviation, whereas they knew extremely little of what the science contained still to be revealed.

A matter having a very great bearing on the future operation of large flying boats was, in Mr. England's opinion, that of re-fuelling in the air, and he asked what was Mr. Sikorsky's attitude towards that particular problem. He asked for Mr. Sikorsky's opinion as to the extent of the extra pay load that could be carried by a flying boat if it were fuelled immediately after it left the water, as compared with taking-off with a full load of fuel, and whether it would be practicable, in Mr. Sikorsky's opinion, to re-fuel large flying boats in mid-Atlantic. If that could be done, it seemed obvious that the pay load could be increased tremendously; it was, to say the least, an interesting speculation.

Major F. M. Green (Fellow): Could Mr. Sikorsky add some further information to his paper and so add still further to its value as a standard work of reference, as undoubtedly it would become? For instance, the horse-power of each of the engines was given as 700; one would like to know exactly what was the rating and at what height that horse-power was obtained. Also, one would like more details of weights of the engine units, wings, and so forth. Such information would be of very great value to English designers.

Finally, Mr. Sikorsky had given many good reasons for adopting high wing loading; but Major Green suggested that there was one more reason which would make them all favour high wing loadings, which was that a very considerable saving of weight was effected.

Lieutenant-Commander the Hon. J. M. SOUTHWELL (Associate Fellow) (*communicated*): Mr. Sikorsky had referred to the close co-operation between his firm and Pan-American Airways. He thought he would agree with him that there was a third partner whom he had omitted to mention—the public.

The public will pay for good service if it is offered to them, but the public will not pay for goods or services unless they are produced first, and it is only with the co-operation of the public that practical experience and development can be obtained. This was a simple economic problem, and he thought it could not be too strongly emphasised that it is not a matter for wet-nursing by ministries, but entirely a matter for the air industry itself.

Air transport has to offer high speed in comparison with surface transport. On overland routes speeds of 180-200 must be achieved, but he questioned whether the same speeds are necessary with oversea routes.

Since for a given speed the seaplane cannot carry as high a percentage of pay load, he suggested that some sacrifice of speed is permissible and desirable.

There are three questions he would like to ask Mr. Sikorsky:—

1. In the S-42 Mr. Sikorsky gives a pay load of 22 per cent. of the gross weight. What would be this figure if the cruising speed were reduced from 157 to 127?
2. Could Mr. Sikorsky give figures of the relative capital cost per ton (or per 1,000lbs.) of pay load capacity of the S-40 and S-42?
3. Mr. Sikorsky gives 65 m.p.h. as the landing speed with a maximum flap angle. Is this with or without the motors?

REPLY TO DISCUSSION

Dealing first with the high wing loading, which is one of the particular characteristics of the S-42, Mr. Sikorsky said he had already mentioned the main considerations in favour of it. Repeating briefly, he pointed out the smooth riding and the good control characteristics in rough air; the high efficiency and increased cruising speed, and the greater safety in stormy weather.

Referring to landing speed characteristics, he said the 65 miles per hour figure had been well established for the S-42 in the fully loaded condition with the engines rotating at zero thrust. This landing speed, which corresponds to a very high lift coefficient, is the result of the combined action of a high lift wing, together with a flap that influenced approximately 75 per cent. of its area.

The landing speed of the S-42 with its wing loading of 28.5lbs. per sq. ft. is identical to that of its predecessor, the S-40, which had a wing loading of only 19.5lbs. per sq. ft. The much higher lift of the S-42, he said, is due to the action of the flap. This was forecast by the results of wind tunnel tests.

Mr. Sikorsky said that the design of the S-42 was outlined with a view to obtaining a wing loading as high as practical and still remain within the 65 m.p.h. limit. He expressed the opinion that it is possible in future designs, still higher wing loadings may be expected.

With respect to the structural struts, he replied that they in no way interfered with the loading of the ship as the forward and aft hatches were far removed from the struts.

With respect to maintenance, he is informed that there has been no trouble, and that the maintenance engineers preferred the straight extruded thick aluminium tube to other types of construction.

All figures of gallonage given in the paper were in terms of United States gallons, based on six lbs., English, per gallon.

Replying to the question of the given weight of the plane with fuel for a 3,000-mile range, Mr. Sikorsky said the gross weight would remain at 38,000lbs. This is possible by reducing the weight empty by completely stripping three

passenger cabins of all non-structural items, such as seats, panellings, carpets, etc.

In the future, however, he expected to increase the gross weight of the ship to 40,000lbs. by using slightly stronger material. The ship had been built of duralumin, 17 ST. There was a new material, known as 24 S, or 24 ST (according to its heat treatment), giving greater structural strength, and the use of this would permit the increase of the gross weight without structural changes. The take-off characteristics left no doubt that the ship would easily take-off with considerably greater load. In that event the landing speed would be increased—not substantially, but to something above the figure now permitted. Therefore, the Government would be asked to issue a double certificate, whereby the ship would be licensed to take-off at a certain weight, but would not be licensed to land at that weight. In that case, if the machine had to land soon after it had taken off, and before it had used much fuel, the pilot would have to drop fuel, and provision would have to be made to enable him to release it quickly in order that when the ship landed its total weight would be within the permitted maximum. He believed that this system was very much recommended for long-distance flying, where the weight of fuel to be carried at the start might amount to 25 or 30 per cent. of the gross weight of the machine—an enormous percentage.

In regard to flying boats, he did not foresee very radical changes in hull designs. He had heard of many attempts and had himself made several attempts to combine other shapes of boats with some kind of vanes or submerged wings, but until now had not obtained satisfactory results.

With reference to the behaviour of the ship in a long swell on the water, Mr. Sikorsky said that perhaps this represented the most severe condition for landing. In that circumstance, a low landing speed may be advantageous, but only if the air was relatively calm; in a stormy wind it would be to the contrary. With respect to the S-42, the plane proved to possess very satisfactory rough sea characteristics. During one of the tests the plane took off and landed 17 times with full load on a reasonably rough day with the waves being fully 6ft. high. It was found that the plane behaved excellently and would stand considerably greater sea if needed. The plane was tested in circling on the water, taking-off, landing, taxying, and so on, repeatedly.

He believed there were most interesting possibilities in the direction of re-fuelling in the air. Re-fuelling immediately after the take-off could certainly be done and would increase the flying range or the pay load. Another interesting possibility would be to re-fuel midway between stages, and by that means one could at least double, and possibly more than double, the useful load that could be carried across the ocean. Based on present aerodynamic information, it could be predicted that a ship of a range of 4,500 miles will allow a pay load of from 7 to 9 per cent. of the gross weight. Within the hull of a flying boat of a gross weight of about 100,000lbs., one could carry 8,000lbs. as pay load, which would be satisfactory to justify trans-oceanic transportation; and by re-fuelling in mid-ocean one could increase the pay load to 15,000 or 20,000lbs. But there was another problem to be faced, that for long journeys one could not keep the passengers in one place, but must provide further accommodation for them. Sleeping accommodations would become necessary, and there must also be a smoking-room and a dining cabin at least. So that while a machine might have the lifting capacity there might not be sufficient room for the passengers to travel in comfort, and one might not be able to use the lifting capacity, which results from re-fuelling, at any rate for passengers.

Replying to Major Green's question concerning the power of the engines, Mr. Sikorsky said that on the S-42 he used a new type of Hornet engine, rated at 700 h.p. at altitudes from zero to 3,000ft. The engines were not highly supercharged; therefore the maximum power was about 730 h.p.

Finally, he expressed again his sincere appreciation of the friendly reception accorded him, and said he would carry away with him most pleasant memories of the occasion and hoped to return to Great Britain in the future.

Vote of Thanks

The President: Mr. Sikorsky was indeed a very remarkable man and it was regrettable that he was not an Englishman. The quality of the applause which had followed the reading of the paper and the reply to the discussion was very much above the average—and that was a significant fact, because the Royal Aeronautical Society was a scientific body, not swayed by sentiment, but one which judged a paper purely on its merits. One could say absolutely without question that Mr. Sikorsky's paper was the sort of contribution the Society wanted more than anything else. (Hear, hear.) One hoped that Mr. Sikorsky would visit this country again even before he built the machine to operate across the Atlantic.

One was particularly delighted that Mr. Sikorsky had the great daring to consider the ordinary " man in the street," who paid for the commercial machine; Mr. Sikorsky had actually taken account of the fact that the passengers on long-distance routes would need sleeping accommodation and would want to walk about, and that if they could not do that they would not travel in the machines. And when all the scientific people had been afraid of loading the machines, for purely technical reasons, he had put forward an overwhelming case for high wing loading, namely, the importance of avoiding air-sickness. From the point of view of " the man in the street " there was very little attraction in air travel, except, of course, its speed; it was a rather dull method of locomotion, rather expensive, a little dangerous and very noisy. However, there was in fact a lot to recommend it, and if air-sickness, which was one of the distressing aspects of aerial travel, could be avoided it was all to the good.

There had been some very lugubrious speeches at that meeting, continued the President, concerning the position of English aviation, and most of them seemed to have been addressed to him, as though he were responsible! Whilst he supposed that he must accept a certain amount of responsibility, he pointed out that if they in this country were behind hand on the technical side of aviation, the people to blame were the members of the Royal Aeronautical Society; it was of no use pushing the blame on to somebody else. But Mr. Sikorsky, by visiting this country at the present time, had caught them, so to speak, " assuming the unperpendicular." However, the position might be represented by a waving curve, and it might well be that before Mr. Sikorsky visited this country again we should be sending some of the members of the Society to America to read papers in his presence.

Meanwhile, the President invited the meeting again to thank Mr. Sikorsky for his model lecture, which was so unassuming and so unboastful, and to show their admiration for Mr. Sikorsky himself.

THIRTY YEARS OF THEORETICAL AND EXPERIMENTAL RESEARCH IN FLUID MECHANICS

BY

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PREFACE

Before proceeding to a brief description of my work in fluid mechanics, I wish to express to the Royal Aeronautical Society my sincere gratitude for the honour paid to me by publishing this account in the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

This account consists of four chapters:—

CHAPTER I.—A description of the Aerodynamic Institute of Koutchino, its foundation and organisation.

CHAPTER II.—Researches pursued during the period from 1904 to 1909, when the Aerodynamic Institute of Koutchino appears to have been the only large laboratory specially constructed and fitted for the purpose of systematic research on the scientific bases of aviation.

CHAPTER III.—Researches carried on in 1910-1918. During those years the Institute of Koutchino worked on a parallel with other aerodynamic laboratories, some of which were equipped on a larger scale.

CHAPTER IV.—Covers the period from 1919 to 1934, during which I had to work outside my own country. Owing to the friendly sympathy of M. Paul Painlevé and M. Henri Villat, the distinguished promoters of systematic research in fluid mechanics in France, and under the auspices of the Research Department of the Air Ministry, I was able to continue my scientific work at the Paris University, as Associate-Director of the Laboratory of Fluid Mechanics.

When comparing my investigations with those published by other authors, and in my comments thereon, I may sometimes depart from strict chronological order and express also my present views upon the subjects under consideration.

The whole of thirty years' work can hardly be very briefly summarised, therefore only such researches are mentioned here as appear to the author to be of special interest at the present moment.

It is difficult to give an account of one's own work without, perhaps, incurring the suspicion of overrating its importance; if readers feel I have trespassed in this sense, I must plead for indulgence.

D. RIABOUCHINSKY.

November, 1934.

Chapter I.

The Aerodynamic Institute of Koutchino

In the spring of 1904, when echoes of the Brothers Wright first flights began to be known in Europe, the author founded at Koutchino, near Moscow, on his family estate, the Aerodynamic Institute of Koutchino.

Air is the fluid meant by the term " aerodynamic " and artificial flight was the most important of the applications included in the programme of the Institute; foreseeing, however, the importance of comparative researches in air and water, the author chose intentionally a location particularly suitable for hydraulic experiments. A small river, dammed so as to form a pond, afforded the possibility of regulating the speed of the current at will, and since 1905 parallel researches were carried on in the wind tunnel and in the stream of water.

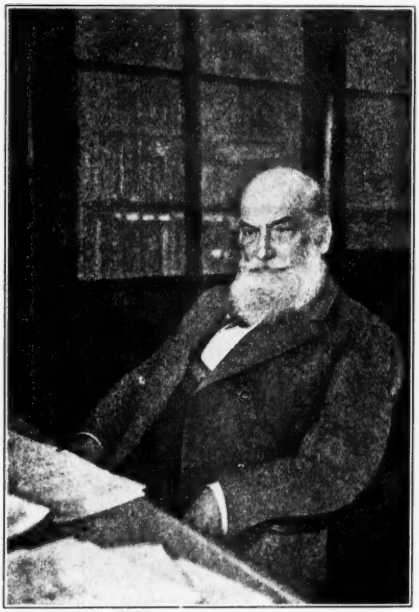


Fig. 1.

The idea of such an institute was very favourably received in the Russian scientific circles. When the author asked N. E. Joukovsky, V. V. Kouznetzoff and S. S. Nejdanovsky to participate in the organisation of this institution, they willingly gave their assent. The author has pleasure in recording what the institute owed to their collaboration.

Professor N. E. Joukovsky had constructed in 1902 a small wind tunnel in the Laboratory of Applied Mechanics of the Moscow University. His experience was taken into consideration by the author for the construction of the large wind tunnel at the Institute of Koutchino.

The first measurements of the axial velocity of the air flow behind a stationary airscrew and the comparison of the thrust measured directly to that calculated by the momentum were undertaken by the author in co-operation with

Prof. Joukovsky. Similar experiments were carried on in England by W. G. Walker and Patrick Alexander in 1900 (*Engineering*, page 233).

The author's investigations on autorotation of plates around axes parallel to the stream, much interested Prof. Joukovsky and he proceeded to the study of plates set into autorotation around axes perpendicular to the stream. In connection with those investigations Joukovsky arrived at the well-known generalisation of Lord Rayleigh's formula, which is usually referred to as the Kutta-Joukovsky theorem. Joukovsky expounded his researches on this subject in two papers published in 1906. The first of these, " On adjoined eddies," written in Russian, in the " Transactions of the Physical Section of the Friends of the Natural Sciences " (Moscow, Vol. 13, No. 2); the second, in French, entitled " De la chûte dans l'air de corps légers de forme allongée, animés d'un mouvement rotatoire," was published in the first issue of the " Bulletin de Koutchino."

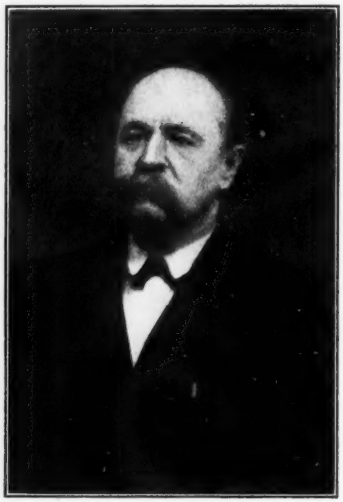


FIG. 2.

Professor Joukovsky participated in the work of the Aerodynamic Institute up to the middle of 1906. After this he gave all his attention to the aerodynamic laboratories of the Moscow University and of the Moscow Superior Technical School; between those laboratories on the one part and the Institute of Koutchino on the other part, there arose a friendly rivalry.

For the second issue of the " Bulletin de Koutchino," printed in January, 1909, Prof. Joukovsky gave a theoretical paper, entitled " Essai sur la détermination théorique de l'effet du courant aérien dirigé dans le plan de l'hélice."

Fig. 1 shows a portrait of Joukovsky, placed by the author, together with those of Boussinesq and Osborne Reynolds, in the hall of the Laboratoire de Mécanique des Fluides of the Paris University.

Pursuing its chief object, the study of motion and resistance of fluids, the Institute of Koutchino also took part in the international launching of " ballons-sondes " for the study of high regions of the atmosphere and organised in 1905 a set of daily kite ascensions. Those researches were under the direction of Prof. V. V. Kouznetzoff, head of the Aerological Observatory of Pavlovsk.

The following papers of Kouznetzoff are included in the first issue of the "Bulletin de Koutchino":—"Premiers lancés de ballons-sondes à l'Institut Aérodynamique de Koutchino," "Détermination de la hauteur des nuages pendant la nuit au moyen d'un projecteur électrique," "Ascension du ballon monté 'General Vannovsky' le 27 Juin, 1905."

In the fifth issue of the "Bulletin de Koutchino," Prof. Kouznetzoff published all the results concerning the study of high regions of the atmosphere

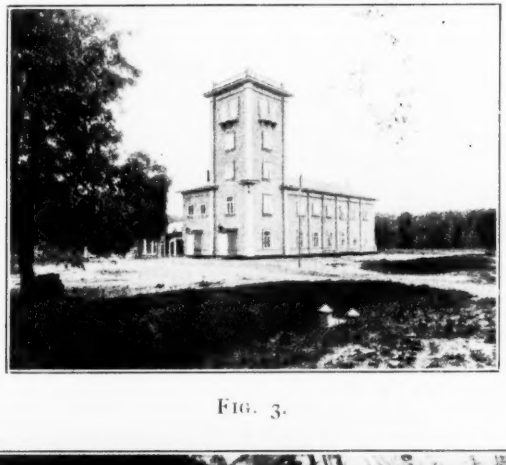


FIG. 3.

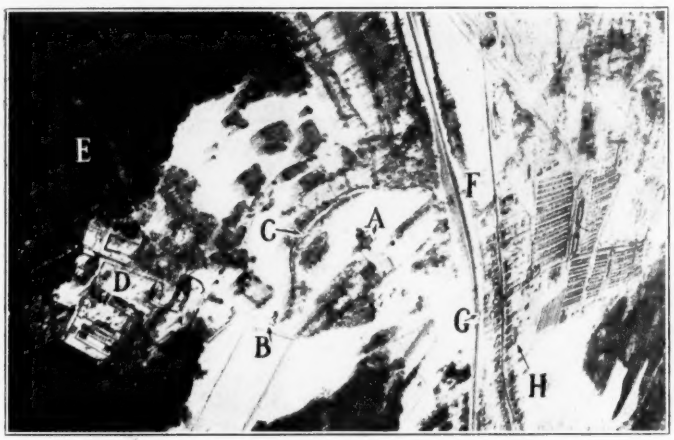


FIG. 4.

collected in Koutchino during a period of ten years. Those researches provided data which permitted him to calculate the yearly variation of temperature up to an altitude of 12 kilometres over the region of Moscow.

Fig. 2 shows the portrait of V. V. Kouznetzoff, whose co-operation was most valuable for the organisation of the Institute.

Engineer S. S. Nejdanovsky, who was for many years interested in the problem of artificial flight, carried out in Koutchino researches on different types

of kites, soarers, and aeroplane models. He worked on taking photographs from kites and constructed in 1904 a sleigh propelled by an airscrew.

The author would like to mention here those of his assistants who worked with him at Koutchino for many years—Mr. V. V. Kovaleff, Mr. P. A. Gousseff

FIG. 5.

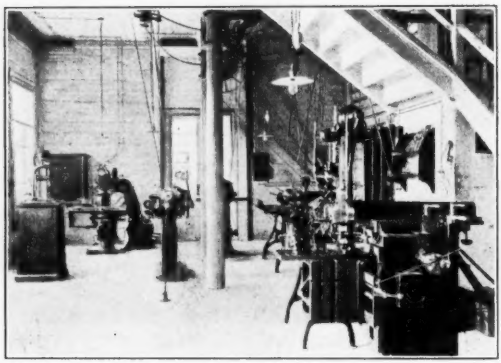


FIG. 6.

and Mr. I. W. Smirnoff. He is glad that Mr. Kovaleff is again at present his assistant.

In June, 1905, the author published a booklet, in French, containing a description of the Aerodynamic Institute of Koutchino and some of the apparatus constructed there. Figs. from 3 to 11 are reproduced from this publication.

Fig. 3 shows the main building of the institute, comprising a large hall, several smaller-sized rooms and a square tower 20 metres high. The tower served to measure air resistance on falling bodies. Its winding staircase led to the roof, from which small models of sailplanes were launched for the purpose of studying their stability.

Fig. 4 gives a general view of the locality where the institute is situated. This landscape view was taken in winter from a kite by Mr. Nejdanovsky. One

FIG. 7.

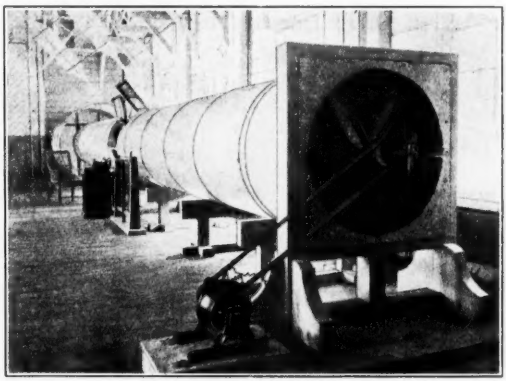


FIG. 8.

can see on this photograph the main building A, the pond B and the stream C, which was utilised for experiments in water. On the other bank of the river is seen the Koutchino estate with its house and dependencies D surrounded by the park E. The railroad F is the Moscow-Nijni-Novgorod line. The Koutchino station and village of same name are seen under G and H.

Figs. 5 and 6 show the power station and the workshop, Fig. 7 the library. Fig. 8 represents the wind tunnel which was 14.5 metres in length. The diameter of its circular section was 1.2 metres. The maximum speed was 6 metres per second. Owing to the asymetrical situation of the tunnel in the hall, the author

had to fit the inflow aperture of the tube with a clockwise screen, as can be seen on Fig. 8, left. This contrivance effectively regularised the air flow in the wind channel.

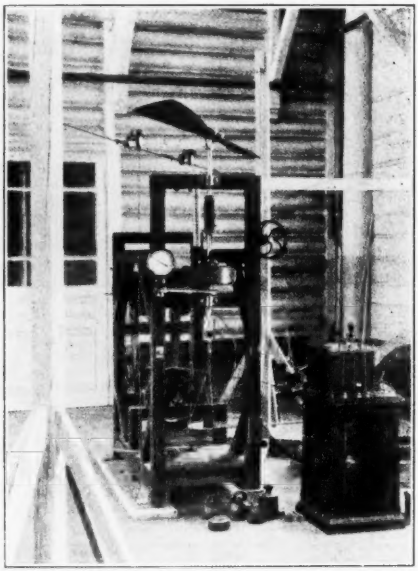


FIG. 9.

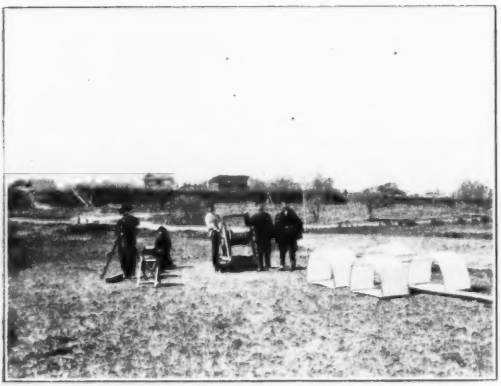


FIG. 10.

Fig. 9 shows the preliminary apparatus for studying airscrews at a fixed point.

Figs. 10 and 11 respectively show the launching of meteorological kites and of a " ballon-sonde."

A few years later, in 1911, the author constructed a special hydrodynamical laboratory, as he termed it, to specify that its object was not only research of an engineering nature, but also researches relating to the fundamental principles of the motion of fluids.

FIG. 11.

FIG. 12.

Fig. 12 gives a general view of the hydrodynamical laboratory. Fig. 13 shows an inside view of the laboratory.

Fig. 14 gives the plan of the laboratory. The water channel was 8 metres long, 2 metres wide and the depth was about 1 metre for a flow velocity of 2 metres per second. The roof and one of the side walls of the channel were of

glass and the roof was fitted with mirrors in order to direct sunrays straight into the water.

Fig. 15 shows an aspect of the hall of the institute in 1912.

Early in 1914 the author included in the programme of the institute the study of gaseous jets, rockets and air resistance at ballistic speeds.

Soon after the outbreak of the world war the Aerodynamic Institute started work in co-operation with the Chief Artillery Committee, studying and testing

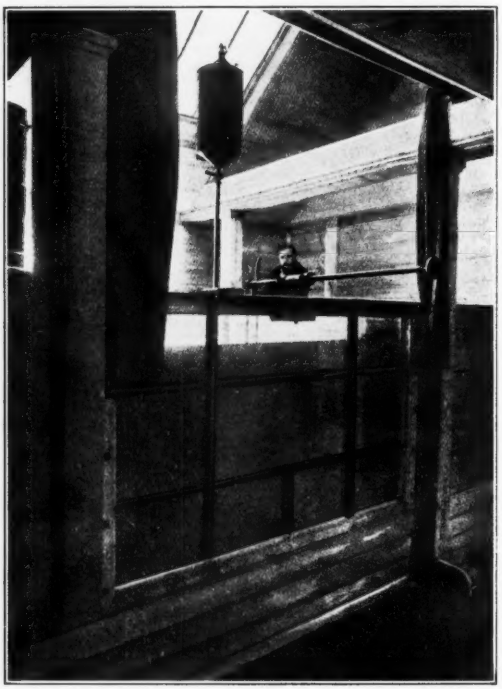


FIG. 13.

apparata submitted to the committee by inventors for the purposes of national defence.

The Institute of Koutchino remained under the personal direction of the author till 1918 when, in order to protect the institute from destruction and to ensure the position of the staff, he took steps for the nationalisation of the institute. A committee composed of the author's university colleagues and of himself was placed at the head of the institute. Soon after, he left Russia.

The author published altogether six issues of the " Bulletin de l'Institut Aérodynamique de Koutchino " which appeared as follows:—First issue in August, 1906,* second issue in January, 1909, the third in December, 1909, the fourth in November, 1912, the fifth in June, 1914, and the sixth, when he was in Paris, in May, 1920. The researches of the author, during the period 1904-1918, related in the six issues of the " Bulletin de l'Institut Aérodynamique de Koutchino," are summarised hereunder in Chapters II and III.

* The second unaltered edition of the first issue was published in 1912.

Chapter II.

Researches Pursued Within the Period 1904–1909

The experiments described in this chapter were made more than a quarter of a century ago. In order to remind readers of the status of aerodynamic researches at that time the author would like to quote the following data:—

Colonel Charles Renard pursued his investigations on lifting airscrews and on airships; his early death in 1905 put an end to this useful work.

Professor Zahm published in 1904, at Washington, an account of his well-known researches on skin friction of tin plates in a wind tunnel.

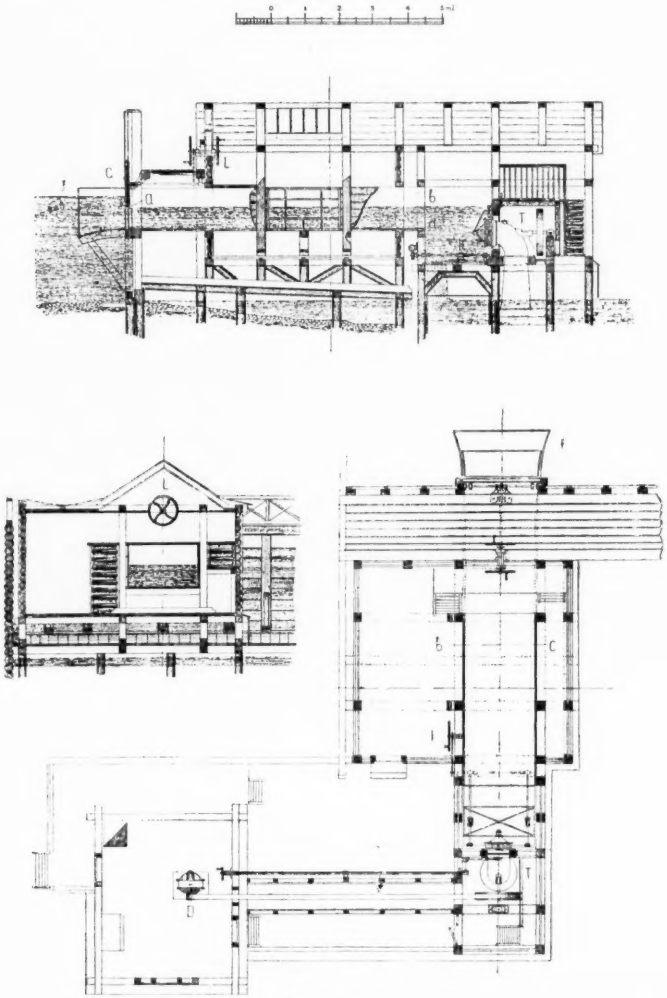


Fig. 14.

Captain Crocco (now General), of the Brigada Specialisti in Rome, was studying the aerodynamics of airships.

F. W. Lanchester's " Aerodynamics " was issued at the end of 1907.

The Advisory Committee for Aeronautics was formed in April, 1909.

The first Eiffel wind tunnel began to function in Paris at the end of 1909.

The " Zeitschrift für Flugtechnik und Motorluftsschiffahrt," a periodical giving an account of the first systematical laboratory researches made in Germany, issued its first number in January, 1910.

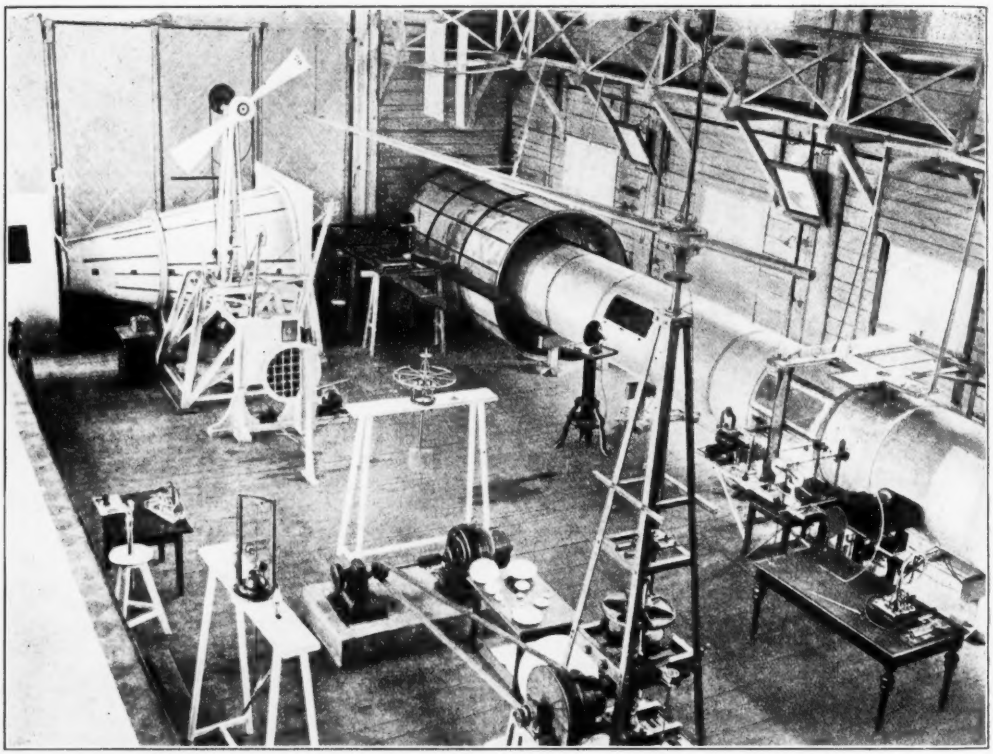


FIG. 15.

1. *Autorotation*

After having constructed the wind tunnel shown on Fig. 8, regulated the airflow and carefully studied the repartition of velocities, the author took as the first object of his investigations the phenomenon designated by him under the name of " autorotation." This term appears to be now generally adopted in aerodynamics, but in a wider sense. At first it was applied to the case when a solid can be set rotating in a stream indifferently in either direction according to the initial impulse received. Now, the term " autorotation " is often used to mean any rotation of a body going on automatically in a relative stream.

One is indebted to Lilienthal for the interesting discovery that, for certain angles of incidence, the resultant force on a curved aerofoil can be not only

perpendicular to the chord, but even deviate towards the leading edge of the wing. An interesting application of this observation was made by the Danish scientist Paul la Cour,* who constructed a windmill, the wings of which were incurved surfaces that had not been submitted to torsion. This windmill could revolve indifferently in both directions, according to the impulse received. Paul la Cour considered† as obvious that if the wings were not curved but plane, a deviation of the resultant force towards the leading edge would be impossible.

At the Fourth International Congress of Scientific Aerostating in St. Petersburg in 1905 Mr. Patrick Alexander demonstrated a small rotor, shown on Fig. 16, which could revolve indifferently in both senses.

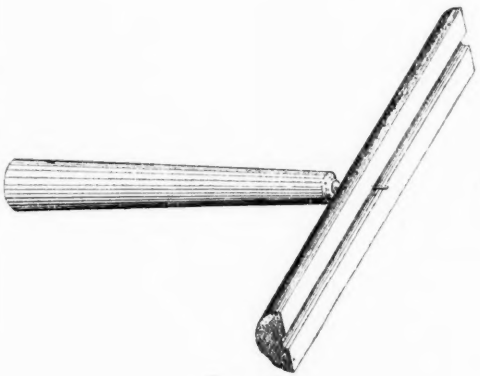


FIG. 16.

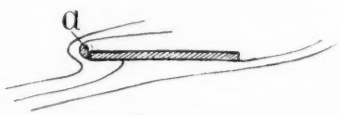


FIG. 17.

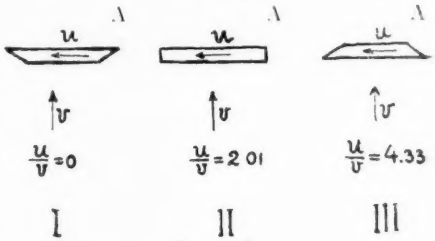


FIG. 18.

The author, considering that the explanation of Patrick Alexander's experiment must be sought in a decrease of pressure which must arise in the vicinity of the leading edge, *a* (Fig. 17), where the radius of curvature of the free streamlines is very small, came to the conclusion that a thin plate can also be set in autorotation. To prove the correctness of this explanation he took a flat aluminium plate, approximately 2 mm. thick, which could revolve round a central axis perpendicular to its plane, and ascertained that this plate could actually be set into autorotation in a stream of air as well as in a stream of water.

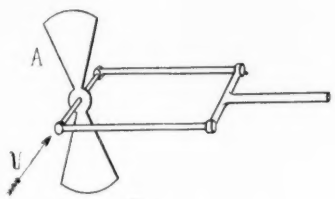


FIG. 19.

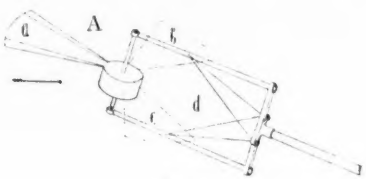


FIG. 20.

The difference of pressure of the two edges of the plate when the rotation becomes uniform is counterbalanced by resistance forces. The author's researches on this case of autorotation were published in 1906 in the first issue of the "Bulletin Aerodynamique de Koutchino."

* Forsog med smoc Mollenmodellen. Ingenioren 1899, p. 62.
† Die Windkraft. Leipzig, 1905, p. 18.

The author will mention in this and in the next sections some of the predicted consequences of this explanation, which were confirmed by experience.

The shape of the leading edge of the plate must play a most important part; hence we can foresee that this phenomenon of autorotation will not occur in Case I, Fig. 18, where V marks the direction of the stream and A a transversal section of the plate.

The experiment (Fig. 19) showed that with a two-bladed sector (central angle $\gamma=45^\circ$, thickness $e=5.1$ mm., diameter $d=30$ cm.) the ratio of the linear

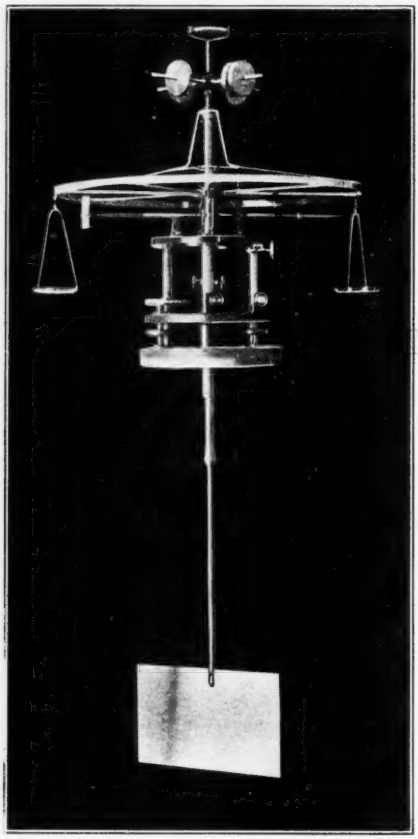


FIG. 21.

speed u at the extremities of the sector to the velocity of the stream V, in Cases I, II and III (Fig. 18), have respectively the values 0, 2.01, 4.33. In Case I the sector does not rotate, in Case III it rotates at fastest; $u:V=4.33$.

The apparatus represented on Fig. 20 was constructed with a view to direct demonstration that, for certain angles of incidence, the resultant force can be deviated towards the leading edge. The plane blade A, perfectly balanced (Fig. 20), occupying position b or c at the moment when the ventilator of the wind channel is set in motion, is drawn or repelled by the wind, according to the

sharp edges or the biased edges being directed towards the wind. In the first case the wing A takes the place a, in the second case it takes place d (Fig. 20).

The " autopropulsive force," *i.e.*, the tangential component of the resultant force, was also measured with the aerodynamic balance shown on Fig. 21.

The author used the non-dimensional drag and lift coefficients $K_x = D/\rho V^2 S$, $K_y = L/\rho V^2 S$, and the normal and tangential coefficient $K_n = R_n/\rho V^2 S$, $K_t = R_t/\rho V^2 S$. Eiffel used the same notation K_x, K_y, but with him they had the dimension of a mass.

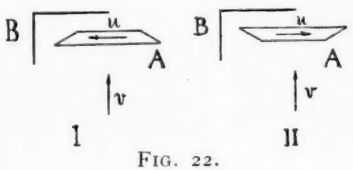


FIG. 22.

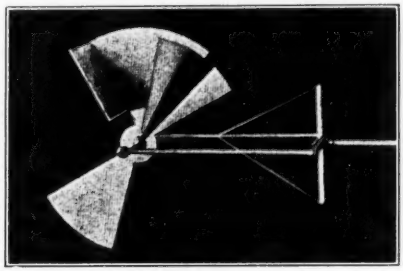


FIG. 23.

The " autorotation method " for studying the efficacy of wings can, in some cases, prove very useful—an example of this will be given in next section.

The study of autorotation in high speed wind and water tunnels could also give interesting results.

2. *A First Approach to the Slotted Wing*

Any contrivance that increases the curvature of streamlines in a flow round a projecting edge accentuates the " pressure decrease " or " suction effect " *behind* the edge.

For instance, when the stream V is orthogonal to the sector A (Fig. 22) this sector is attracted towards the angle B in Case I and pushed away in Case II.

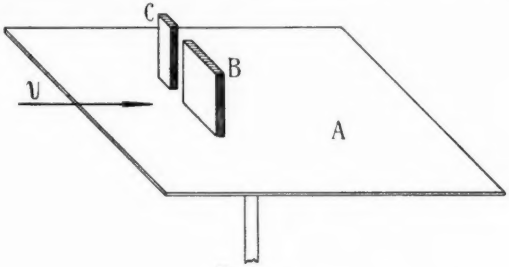


FIG. 24.

Fig. 23 shows the apparatus constructed to demonstrate that this is actually the case.

If we place on the horizontal plate fixed in the middle of the wind tunnel a system of two vertical planes of unequal breadth, as seen on Fig. 24, and sprinkle the plate A with fine powder of lycopodium, we obtain in the air stream the " spectrum " shown in Fig. 25. The method used to obtain this and analogous spectra is described later.

On examining this spectrum, one notices that the streamlines detach themselves from the plates at the points a, c, d (Fig. 26), consequently, in the vicinity of these points the depression must be considerable. Point b, on the contrary, appears to be a point at which velocity is zero, and therefore a point of over pressure.

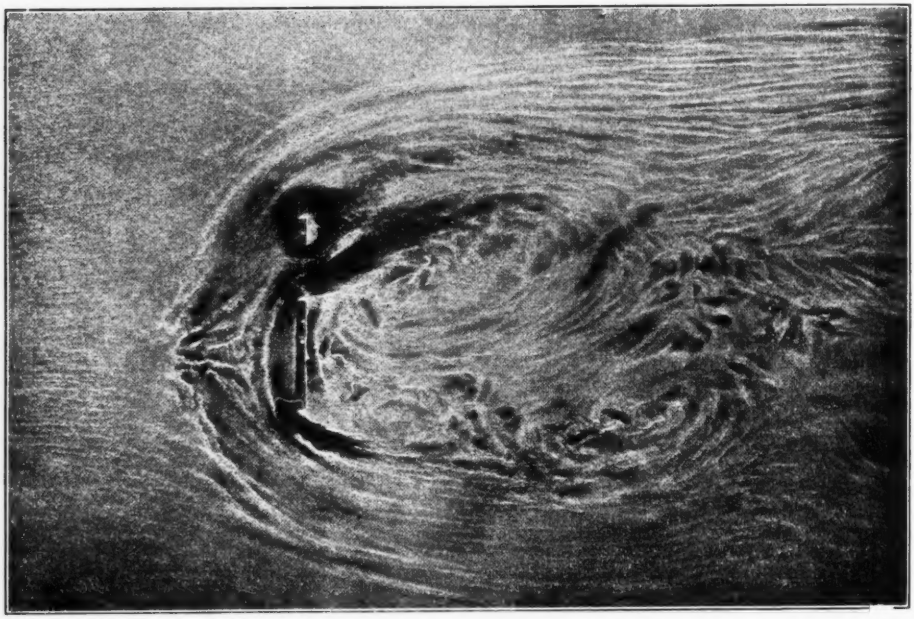


FIG. 25.

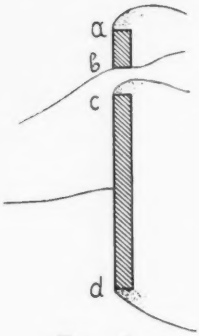


FIG. 26.

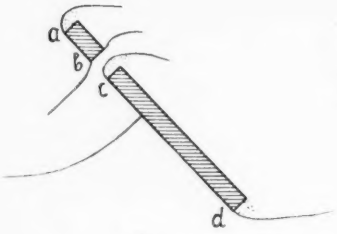


FIG. 27.

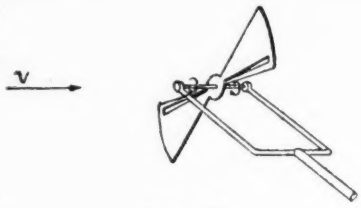


FIG. 28.

The same will happen when the relative stream ceases to be orthogonal to the plane (Fig. 27).

In order to submit this reasoning to experimental verification, the autorotation method was applied. The " slotted sector," " secteur à fente " as the author called it, shown on Fig. 28, starts rotating in a stream in such a way that the edge nearer to the slot is the leading edge.

Upholding the sector, one feels that the moment tending to set the sector revolving is considerable.

The results mentioned above clearly show that a slot made in the vicinity and parallel to the leading edge of a wing modifies the flow of the fluid and accentuates the suction effect in a favourable sense. When mentioning this experiment in 1909, the author realised that this new principle would find some day technical application. This happened, in fact, ten years later, when Mr. Handley Page achieved his fine invention patented in 1919.

Previous to this (*Flight*, Nov. 20, 1914) Dr. A. P. Thurston had studied the problem of interaction of two planes, the one placed at the front being of smaller breadth. He had foreseen the importance of a like arrangement for increasing the stability of aeroplanes.

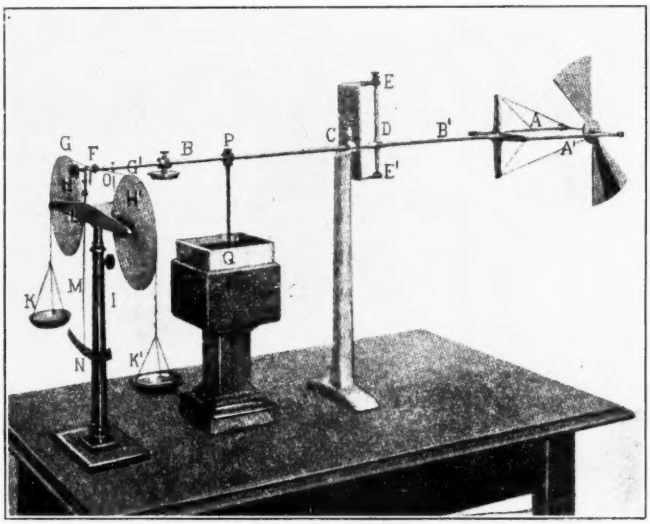


FIG. 29.

3. *Resistance of Rotating Sectors and the Autogiro*

In the first Annual Report of the Aeronautical Society of Great Britain for the year 1866 (p. 19) F. H. Wehnham mentions having found that the pressure exerted by a stream of water on a plate which moves transversally to the stream is greater than that exerted on the same plate when motionless. He adds that the pressure exerted on a plate rotating at high angular speed is equal to the resistance experienced by a disc, the area of which is equal to that swept over by the rotating plate.

A. Dupré (" Théorie mécanique de la chaleur," 1869, p. 468), relying upon experiments made with windmills, also came to the conclusion that a plane placed orthogonally in a current of air suffers a greater pressure when it moves transversally to the stream than when it remains motionless.

In 1905, measuring the pressure exerted by a stream upon sectors in autorotation, the author ascertained that some of the plates he used revolve with sufficient speed to make their resistance equal to that of a disc of same diameter.

The apparata devised for the study of autorotation and for measurement of the pressure exerted on sectors rotating with different angular velocities, in air and in water, are shown on Figs. 29 and 30.

The results obtained in air and in water agree closely.

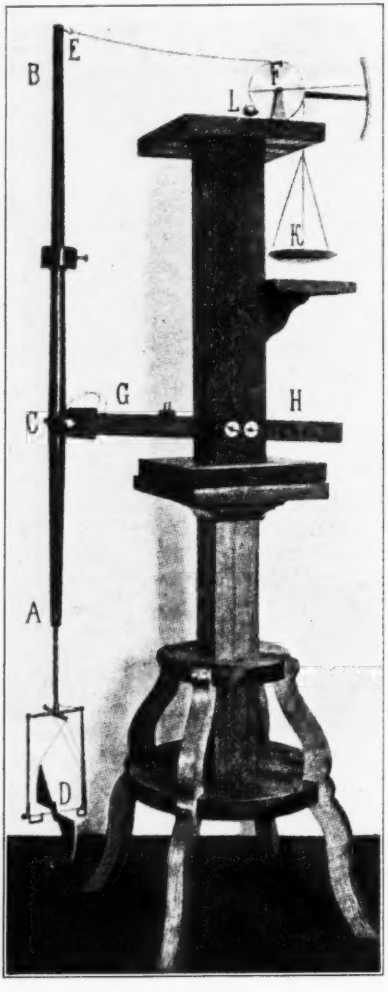


FIG. 30.

The relation between the circumferential speed u of the sector and the wind speed v is approximately expressed by the formula $u = A(v - a)$, in which A and a are coefficients constant for each sector. Coefficient a represents the part of wind speed used to surmount passive resistances. The author gave to A the name of "coefficient of autorotation" and studied the variation of this coefficient and that of the drag coefficient $K = D/\rho SV^2$ as a function of the central angle α of the blades of the "sector."

Fig. 31 shows the set of sectors used in these researches. Their thickness was 1.7 mm.

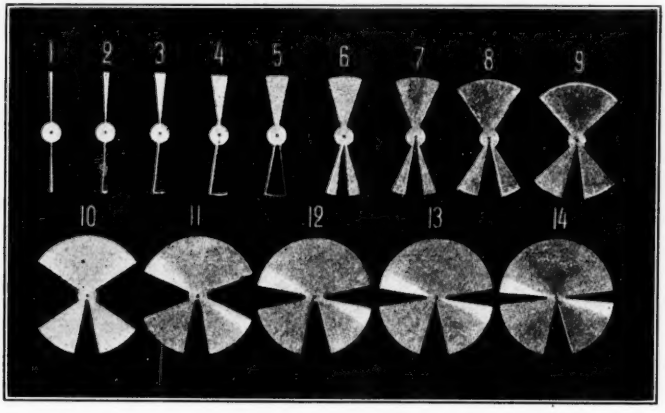


FIG. 31.

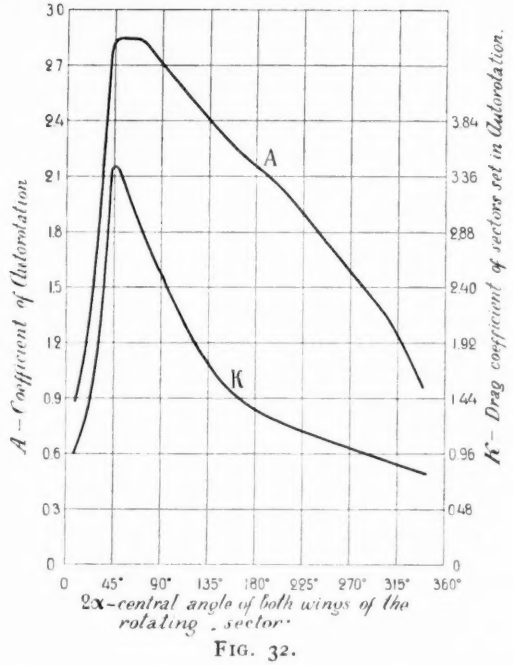


FIG. 32.

As seen on Fig. 32 coefficients A and K attain their maximum value when the central angle of the sector's wings is approximately equal to 22.5°. In these experiments the ratio of the diameter of the sectors to that of the wind tunnel was 1 : 4.

In Fig. 33 the ratio P/P_0, where P is drag of rotating sectors and P_0 drag of circular disc of same diameter in the wind tunnel, is plotted against the ratio S/S_0 of the area of the sector to that of the disc.

The drag of rotating sectors increases at first rapidly with the wing's angle α, and reaches for $2\alpha=90°$ approximately 4/5 of the resistance exerted on a plain disc, and varies but slowly with a further increase of α.

These experiments having been carried on in a tunnel with rigid walls, the increase of resistance due to the influence of these walls must be taken into account. This circumstance leads us to assign on Fig. 33 to ratio P/P_0 corresponding to a plain disc the value 1.15 instead of the value 1.

The dotted straight line expresses approximately the ratio of drag resistance of fixed sectors to that of the plain disc, both being measured in an unlimited stream.

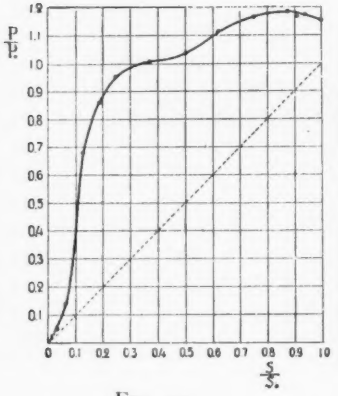


FIG. 33.

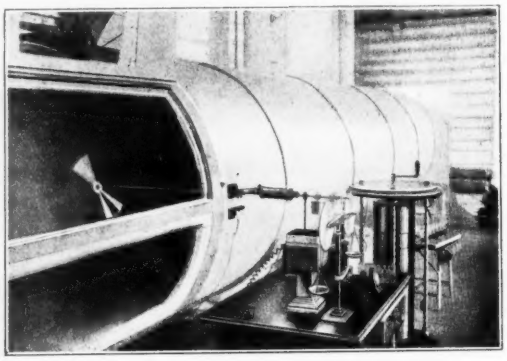


FIG. 34.

We have spoken above of the resistance of sectors set in autorotation, hence for a determined value of the ratio $u:(v-a)$. To study the variation of coefficient K when one gives $u:v$ other values, the author used the apparata shown on Fig. 34, the rotation of the sector being kept up by a small electromotor fixed to the balance seen on the figure. Flat sectors can be considered as screw propellers of zero pitch, and results obtained with them will be mentioned in the next section, when dealing with screw propellers.

The torque was determined from the angular acceleration of the sector when set in autorotation.

The T curve given in Fig. 35 diagrammatically shows the variation of the torque experienced by a rotating sector with the increase of its angular velocity Ω. When $\Omega<\Omega_1$, or $\Omega>\Omega_3$, the torque is negative, viz., resistant to the rotation of the sectors; when $\Omega_1<\Omega<\Omega_2$ the torque is positive or autorotative. If there were no frictional resistance in the pivots, the angular velocity of the sector would be Ω_3; in practice the sectors always have an autorotative angular velocity Ω_2, less than Ω_3 and the sector acts as a windmill.

The apparatus on Fig. 36 was designed to show that, as a consequence of the angular momentum theorem, the rotation about the axis of the outflow will have the same or the opposite sense as the rotation of the sector, according to the torque being positive or negative.

The author expected that in the case of autorotation a single axial vortex is generated, hence that circulation round the axis of the outflow would be approximately independent of the radial distance from the axis. To verify whether the

angular velocity actually increases towards the axis, he placed behind the sector three pairs of small wings which could rotate independently; experience showed that this was right.

If the angular speed of the sector is progressively increased beyond the speed of autorotation, the small wings stop, beginning from the farthest from the axis and, as the speed of rotation continues to increase, the wings start revolving in the same sense as the sector. The author made this experiment for the first time in 1905 and described it in the "Bolletino della Societa Aeronautica Italiana" (No. 2) at the beginning of 1908.

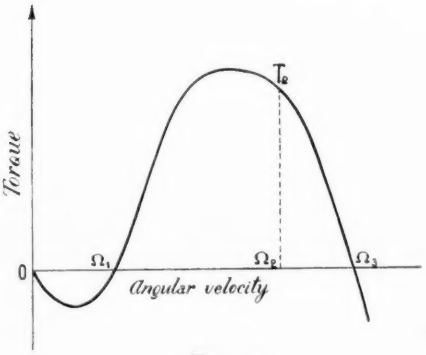


FIG. 35.

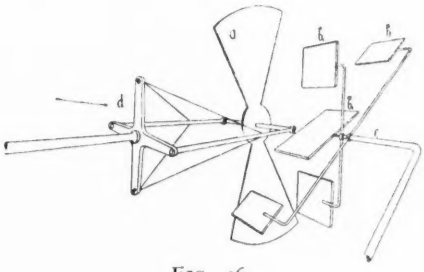


FIG. 36.

In the same paper the following experiment is described: A horizontal plate, covered with black paper, was fixed in the middle of the wind tunnel. A slot was made in this plate at a right angle to the stream and the axis of the rotating sector was placed as shown on Fig. 37.

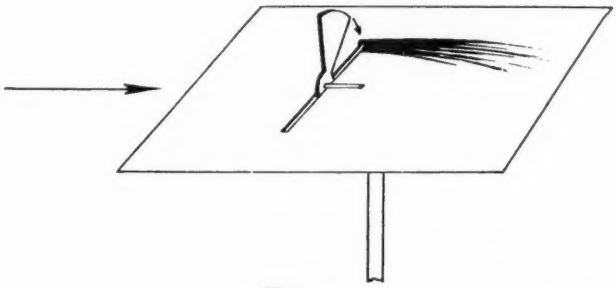


FIG. 37.

The horizontal plate was sprinkled with fine lycopodium powder. When the wind began to blow in the tunnel, and the sector was rotating, the powder was blown off in certain points and the black paper reappeared.

Fig. 38 shows a spectre obtained in this way. Every time that each of the two blades of the rotating sector swept over the horizontal plate, a black line, such as would be produced by the stroke of a whip, was traced in the lycopodium powder. It is interesting to note that this experiment proves that the eddies adjoined to the leading edges of the blades, which left the mark on the plate, are continuously generated as the eddies, already formed, could not pass across the horizontal plate.

The diagram of Fig. 37 corresponds to the case of forced rotation; in the case of autorotation the imprint of the adjoined vortices would appear on the other side of the axis.

The increase of relative velocity, due to the above-mentioned axial vortex (Fig. 36), allows us to explain by Bernouilli's theorem the considerable increase of resistance experienced by rotating sectors.

The author's researches on autorotation were taken into consideration by Mr. de la Cierva in his early work, and he mentioned them in his first report on autogiros in 1920.

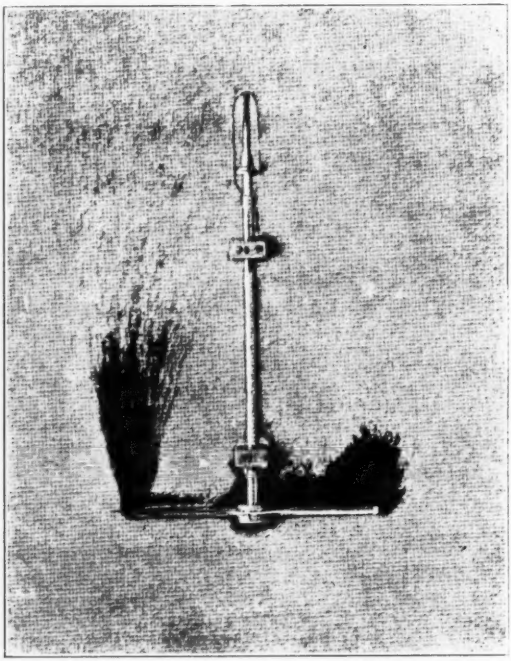


FIG. 38.

At the first " Congrès International de la Sécurité Aérienne " in Paris, in 1930, Mr. de la Cierva's autogiro and Mr. Handley Page's slotted wing were prominent features, and the author was glad to realise that his researches had proved useful in the genesis of these important improvements in the flying machine.

4. *The Airscrew*

The researches on airscrews carried on during the period 1905-1908, were published in the second issue of the " Bulletin de Koutchino," January, 1909. A preliminary note on the functioning of an airscrew in a lateral relative stream had already been published in the first issue of the " Bulletin."

At about the same time, in 1908, R. E. Froude gave an account of the results of his model experiments with steamship screw propellers, which appeared in Trans. Inst. Nav. Arch.

The author carried his curiosity somewhat further, and studied the properties of an airscrew, the axis of which was parallel to the stream, not only in the working condition of a propeller, but also in that of a windmill or an autogiro and in that of a "brake." In his investigations he did not seek for a screw propeller of high efficiency, but, by giving to the propellers a simple geometrical shape, he endeavoured to elucidate the general rules of their functioning.

The airscrews tested in the wind tunnel were of constant pitch and the two sides of the airscrew's blades were perfectly symmetrical. The sections of one of these screw wings is seen on Fig. 39.

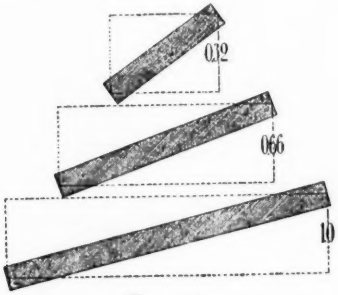


FIG. 39.

The pitch ratio varied from zero (flat sector) to 3; the diameter d was uniformly 30 cm.

The diameter of airscrews tested at a fixed point was 0.3, 2, 3 and 4 metres.

Non-dimensional coefficients for the thrust Q and the torque power T of airscrews were chosen as follows:—

$$\alpha = Q/\rho S n^2 r^2, \quad \beta = T/\tfrac{1}{2}\rho S n^3 r^3,$$

where $S = \pi r^2$ is the area of the airscrew disc.

The efficiency E of a stationary airscrew was defined as the ratio

$$E = T_1/T = (Q^3/4\rho S T^2)^{\frac{1}{2}} = (\alpha^3/\beta^2)^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad (1)$$

where T_1 is the power put into an ideal stationary screw of same diameter and giving the same thrust as the actual screw, whose only loss of energy is represented by the kinetic energy of the axial velocity V_2 uniformly distributed in the circular section of the slipstream.

$$Q_1 = Q = \rho S V_2^2, \quad T_1 = \tfrac{1}{2}\rho S V_2^3.$$

In the paper referred to, the author already noted the importance of the non-dimensional parameter V/nd, but does not use it for graphical representation of experimental data. In the third issue of the "Bulletin de l'Institut Aerodynamique de Koutchino" (December, 1909), however, the author explicitly introduces the expression

$$Q/\rho S V^2 = f(V/nd)$$

and notes the remarkable simplifications which can be attained in aerodynamics by using the number V/nd. The figure in which the author first used this number is shown in the section in which the problem of rotors is examined (Fig. 80).

In these investigations the author applied the two theories which were known at that time. The first is that of Froude-Drzewiecki, in which the force on each elementary portion of the blade surface is separately estimated from the relation $R = \rho S V^2 f(i)$ between the force experienced by a rectangular flat plane and the incidence angle i. The second is the momentum theory.

When applying the first of these theories, the author admitted that

$$f(i) = \sin 2i, \quad i < 45^\circ,$$
$$f(i) = 1, \quad i > 45^\circ.$$

To show that this theory can be applied as first approximation only when the central angle and the number of blades of a stationary airscrew are small, some calculations were made for comparing with experimental data.

On Fig. 40 the calculated efficiency E of a stationary screw, each of the two blades of which has a central angle of 18°, is plotted against the pitch-ratio. The influence of the thickness of the blades, which have the shape shown on Fig. 39, was taken into consideration for calculation. The agreement between theory (plain curve) and experiments (separate points) is rather good in this case.

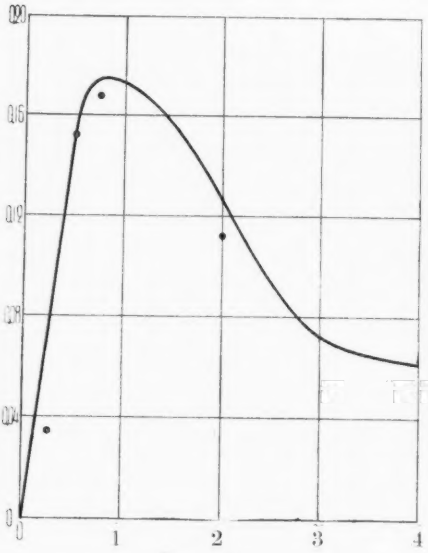


FIG. 40.

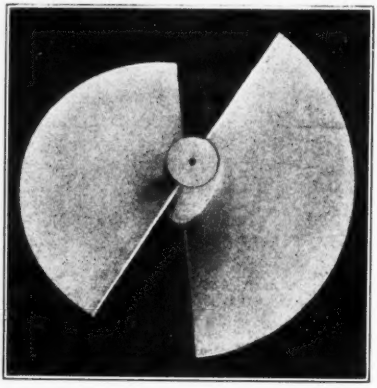


FIG. 41.

This, however, is not so when the central angle γ of the blades is not small. Table I gives the thrust and power coefficients of a set of stationary two-blade screws of different central angles with the same diameter 2 m. One of these screws is shown on Fig. 41.

TABLE I.

γ	α	β	E	K_α	K_ρ	K_α/K_β
12°	0.490	2.43	0.141	0.731	0.558	1.240
18°	0.648	3.10	0.168	0.623	0.590	1.060
22½°	0.803	3.85	0.187	0.608	0.633	0.961
30°	0.923	4.64	0.191	0.519	0.621	0.836
36°	0.957	4.48	0.209	0.445	0.525	0.848
40°	1.090	5.01	0.227	0.438	0.538	0.814
60°	1.220	5.11	0.263	0.335	0.390	0.851
72°	1.240	6.04	0.228	0.283	0.397	0.713
97°	1.510	7.11	0.261	0.256	0.359	0.713
144°	1.740	7.45	0.308	0.196	0.262	0.748

The thrust and torque coefficients K_α, K_β, which figure in Table I, were obtained by comparing empirical coefficients α, β, given in that table, with the theoretical values of the same coefficients. Coefficients K_α, K_β, remain approximately constant, only for small values of γ and rapidly decrease with further

increase of the central angle. Fig. 42 gives coefficients α, β and efficiency E as functions of the central angle γ.

The same thing happens in the case of multi-bladed screws. Fig. 43 gives coefficients α, β and efficiency E as functions of the number of blades. The sections of blades of these screws are shown on Fig. 44. The number of blades varied between one and eleven. The eleven-blade screw is shown on Fig. 45.

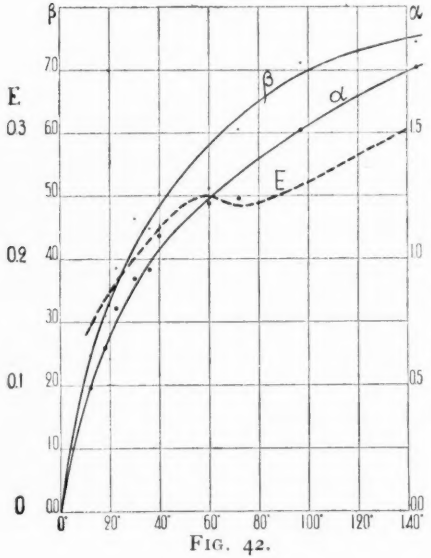


FIG. 42.

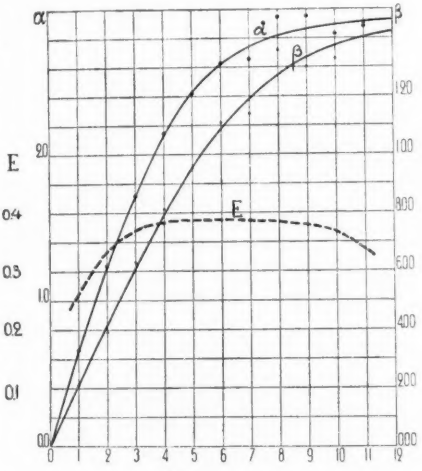


FIG. 43.

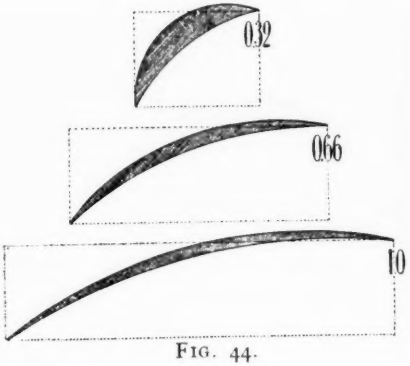


FIG. 44.

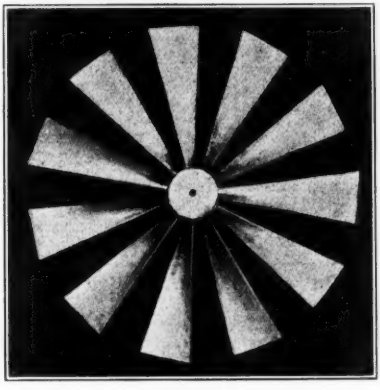


FIG. 45.

When the number of blades exceeds three or four, coefficients α and β cease to increase in proportion to the number of blades. The deficiency of the Froude-Drzewiecki theory appears even more clearly in the following experiment. Curve a, represented on Fig. 46, gives the variation of resistance of the sector

shown on Fig. 47, revolving around an axis parallel to the stream ($V=4.9$ m./s., $d=0.3$ m., $\gamma=45°$). The dotted curve was calculated, applying W. Froude's method. Except for very small angular speeds, the discrepancy between theory and experiment is considerable.

In applying this theory to a screw propeller, the author obtained for a pitch ratio $h/d=0.75$ the equation

$$Q/\rho S n^2 r^2 = 0.684 - 0.390\,(V/nr) - 0.711\,(V^2/n^2r^2).$$

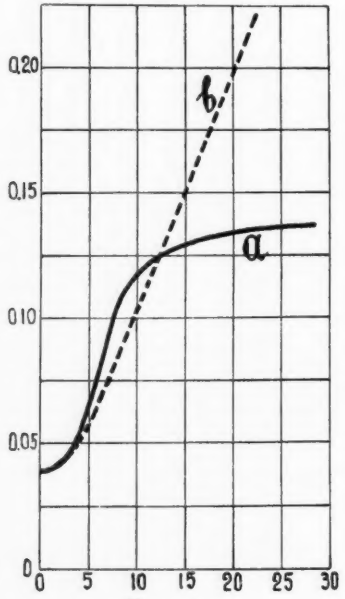


FIG. 46.

FIG. 47.

The numerical value of these coefficients considerably differs from that deduced by experiment.

To study the effect of the shape of the leading and trailing edges and that of the shape of the tips of the blades, tests were made with screws, the blade sections of which are shown on Figs. 48, 49 and 50.

The diameter of these screws was 2 metres and the central angles $\gamma=18°$. The initial shape of the blade tips was the same as that of the screw blades indicated on Fig. 45. The convex and concave sides of the blades were parabolas. The author studied first of all the screws A (Fig. 48) and B (Fig. 49) without the borders a and b, after which borders a and b were added; these screws were designed Aa and Bb.

Further, the blade tips of screws *Aa* and *Bb* were shaped as shown on Fig. 51. These two screws are indicated as *Aaa* and *Bbb*. In replacing in the screw *Bbb* border b by border b_1, as shown on Fig. 50, we obtain the screw Bb_1b.

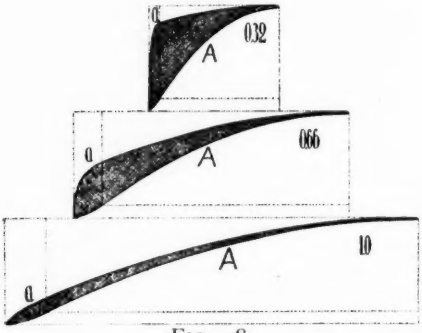


FIG. 48.

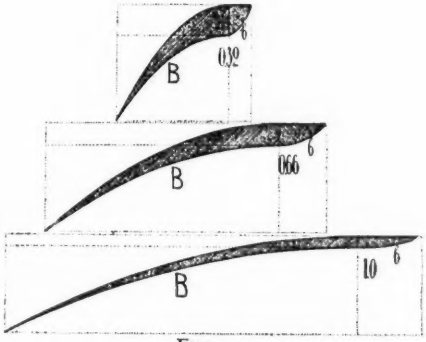


FIG. 49.

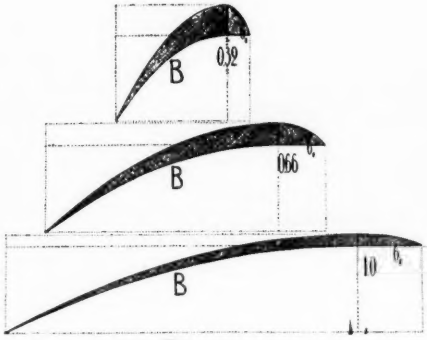


FIG. 50.

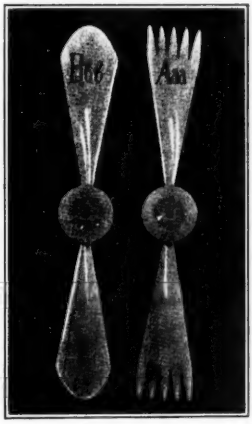


FIG. 51.

Coefficients α and β and the efficiency E of these screws are given in Table II.

TABLE II.

	α	β	E
B	1.050	3.77	0.286
Bb	1.200	3.71	0.355
Bbb	1.050	2.62	0.411
Bb_1b	1.050	2.98	0.360
A	0.953	2.68	0.346
Aa	1.040	3.00	0.355
Aaa	0.853	2.59	0.304

One can note that the efficiency of screw Bbb is higher than that of screw Bb_1b. The great influence of the shape of blade tips is clearly seen from data given in Table II.

When applying the momentum theory the author came upon certain points insufficiently elucidated at that time.

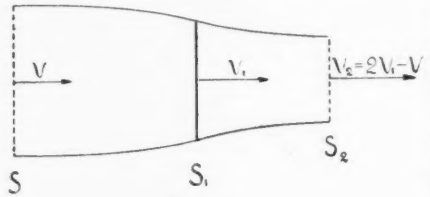


FIG. 52.

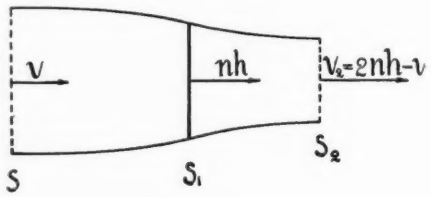


FIG. 53.

R. E. Froude, in developing the theory of the actuator (Fig. 52), obtained for thrust Q and torque power T the relations

$$Q=2\rho S_1 V_1 (V_1-V),\ T=QV_1,\ V_1=\tfrac{1}{2}(V_2+V).$$

In applying these formulæ to an actual screw of constant pitch h, R. E. Froude took in account the relation $T=Qnh$ and thus obtained an expression of the form

$$Q=\alpha\rho S_1 r^2 n^2 (1-V/nh) \quad . \quad . \quad . \quad . \quad (2)$$

In 1908 R. E. Froude expressed the experimental results which he obtained by formula

$$Q=\alpha\rho S_1 r^2 n^2 (1-V/nh)(1-0.08\,V/nh) \quad . \quad . \quad . \quad (3)$$

The notations are those of the present author.

The term $0.08\,(V/nh)$ being comparatively small, the experimental results appear to confirm formula (2).

In the author's experimental researches on airscrews, coefficient a_2, of formula

$$Q=\alpha\rho S_1 n^2 r^2 (1-a_1\,V/nh-a_2\,V^2/n^2h^2)$$

appears as much more important than that indicated by R. E. Froude, and it is, on the contrary, coefficient a_1 which appears to be, in some cases, negligible.

For constant pitch screws, the shape of which is shown on Fig. 39, the author has been able to express results obtained by the formula:—

$$Q=\alpha\rho S_1 n^2 r^2 (1-V^2/n^2h^2) \quad . \quad . \quad . \quad . \quad (4)$$

which does not agree as well with formula (2) as R. E. Froude's formula (3).

But there are stronger objections against the application of formula (2) in all cases.

In studying the repartition of velocities in the slipstream behind a stationary airscrew of pitch h, the author never observed axial velocities V of the rate $2nh$. The velocities which he observed tended towards nh without ever exceeding this limit. In many cases the interaction between a solid and the fluid can be compared to the shock of a solid against a perfectly soft body, and in these conditions the fluid mass repelled by the screw cannot exceed the value nh.

The author, guided by this reasoning, demonstrated the following proposition: For a stationary screw of constant pitch the limiting value of the efficiency E is 0.5.

In fact, to obtain a maximum thrust for a given power the velocities in the outflow must be uniformly distributed. On the other hand, according to the hypothesis just made, the maximum value of V_2 is equal to nh. Therefore, for a screw of constant pitch, of maximum efficiency, thrust and power are

$$Q=\rho S_1 n^2 h^2,\ T=Qnh=\rho S_1 n^3 h^3.$$

In comparing these equations to equations (1), we have

$$E = (Q^3/4\rho S_1 T^2)^{\frac{1}{2}} = \tfrac{1}{2}.$$

It results therefrom that at least half of the power put into a stationary screw of constant pitch is necessarily transformed into heat by shock and friction, when passing through the screw.

This reasoning has been confirmed by experience. After having studied in detail the motion of air around a screw revolving at a fixed point, the author calculated the torque power T, applying the angular momentum theorem. He next calculated the kinetic energy T_1 of air passing in unit time through a straight section of the slipstream. He found that T approximately equals $2T_1$. This confirms the remark made above, as in the application of the theorem of angular

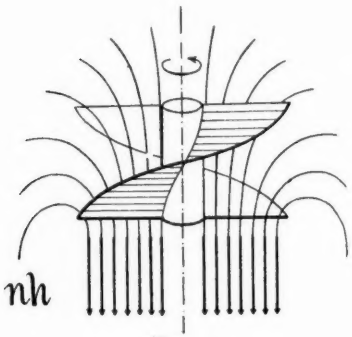


FIG. 54.

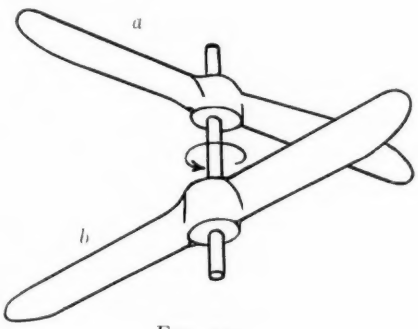


FIG. 55.

momentum, the work of interior forces is not to be taken into account, whereas in applying the theorem of energy, the latter must be taken into consideration.

Direct measurement of thrust and torque has also confirmed the above reasoning; the efficiency E did not exceed the value $\frac{1}{2}$ for any of the constant pitch screws tested.

On proving this theorem the restriction that the pitch of the screw is constant has a primary importance. Supposing that the screw represents a system of two screws—a and b—of constant but not equal pitch set on the same axis (Fig. 55) and that pitch h_b of screw b is higher than pitch h_a of screw a, whence we can write

$$Q = Q_a + Q_b = \rho S_1 n^2 h_b^2$$
$$T = n\,(Q_a h_a + Q_b h_b) = Qnh$$

where

$$h = (Q_a h_a + Q_b h_b)/(Q_a + Q_b) < h_b$$

and, therefore, it may happen that

$$E > \tfrac{1}{2}.$$

It has been possible, in fact, to construct screws, the efficiency E of which reaches and even exceeds the value $\frac{1}{2}$.

An interpretation can now be given of the divergence between Froude's formula (2) and the author's formula (4).

The actuator can be defined as a screw, pitch h of which tends to zero and number n of revolutions in unit time to infinity, whilst the product nh conserves a constant value.

If the central angle γ of the screw blades is large, we can compare the screw propeller to a "many-sheeted actuator." According to diagram B of Fig. 56 the

thrust Q and torque power T of such a screw propeller may be expressed as follows :—

$$\alpha' = Q/\rho\pi r^2 n^2 h^2 = (1 - V/nh), \quad \beta' = T/\tfrac{1}{2}\pi r^2 n^3 h^3 = (1 - V^2/n^2 h^2),$$

where $\alpha' = \alpha h^2/r^2$, $\beta' = \beta h^3/r^3$. In the case of a screw of constant pitch, shocks must occur and torque power T_1 will be

$$T_1 = T + \tfrac{1}{2}\rho\pi r^2 nh\ (nh - V)^2 = Qnh.$$

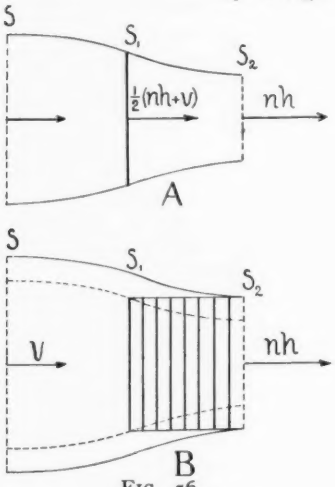


FIG. 56.

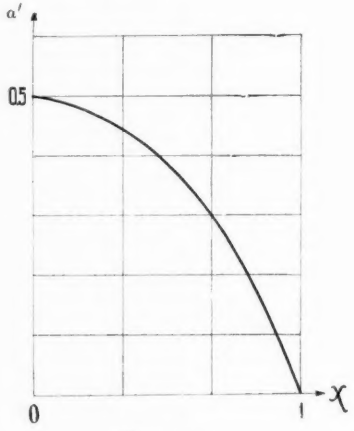


FIG. 57.

In the case of narrow-blade airscrew, diagram A on Fig. 56, corresponding to a single actuator, can be applied, and we have

$$\alpha' = Q/\rho\pi r^2 n^2 h^2 = \tfrac{1}{2}\ (1 - V^2/n^2 h^2) \quad . \quad . \quad . \quad . \quad (6)$$

$$\beta' = T/\tfrac{1}{2}\rho\pi r^2 n^3 h^3 = \tfrac{1}{2}\ (1 + V/nh)\ (1 - V^2/n^2 h^2) \quad . \quad . \quad . \quad (7)$$

and, in the case of a narrow blade screw of constant pitch,

$$T_1 = T + \tfrac{1}{2}\rho\pi r^2\ [(nh + V)/2]\ (nh - V)^2 = Qnh.$$

On Figs. 57 and 58 the values of the thrust and torque power coefficients α' and β, defined by equations (6) and (7), are plotted against $\lambda = V/nh$. The β'

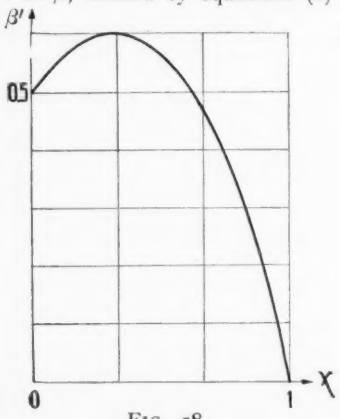


FIG. 58.

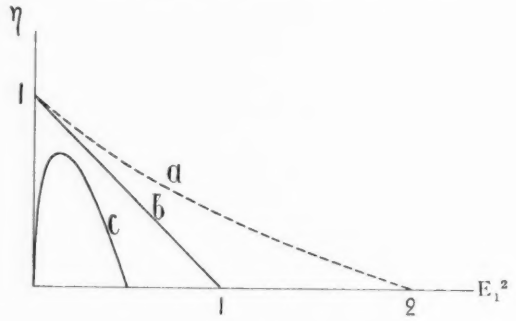


FIG. 59.

curve has a maximum corresponding to the value $\lambda=\frac{1}{3}$, whilst the a' curve is decreasing steadily. It is interesting to note that screw propellers often show this peculiarity.

The diagram on Fig. 56*b* corresponds to Froude's experimental formula (3) and the diagram on Fig. 56*a* to the author's formula (4).

In intermediate cases the corresponding formulæ may be expressed, if using only one parameter, as follows:—

$$a=[(1-\epsilon/2)+(\epsilon/2)\,(V/nh)]\,(1-V/nh)$$
$$\beta=[(1-\epsilon/2)+(\epsilon/2)\,(V/nh)]\,(1-V^2/n^2h^2)$$

where ϵ may take any value from 0 to 1.

Upon a more detailed examination of the matter, it would obviously be necessary to take into consideration the fact that the pitch determined by zero thrust is always less than the pitch determined by the zero torque.

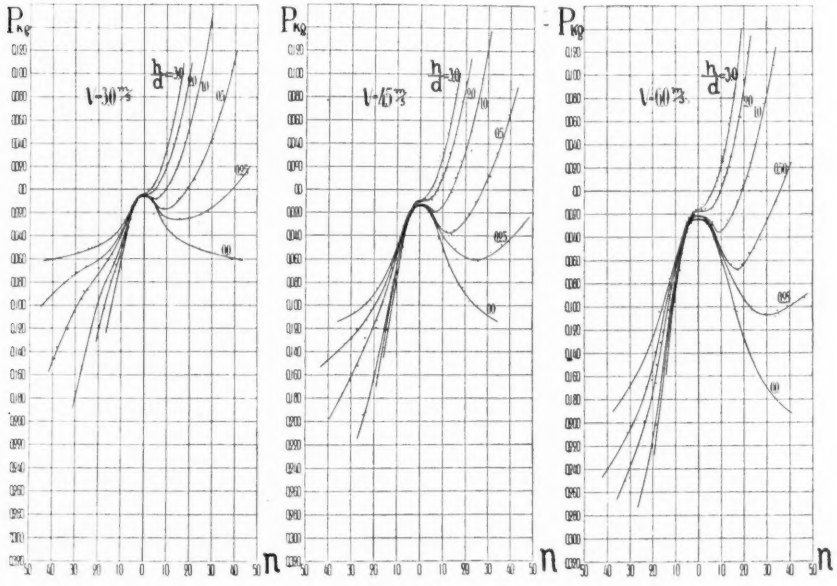


FIG. 60.

In applied aerodynamics it is useful to know the characteristics, not only of a screw propeller, but also those of stationary screws, and the author considers that it would be rational to characterise the functioning of airscrews by an expression of the form

$$QV/T=f\,(Q^3/2S_1\rho T^2),$$

or, by noting

$$\eta=QV/T,\ E_1=(Q^3/2S_1\rho T^2)^{\frac{1}{2}}=\sqrt{2}E,$$

by the expression

$$\eta=f\,(E_1).$$

According to diagram *A* or *B* of Fig. 56 being adopted, we have respectively as limiting forms of function f:—

(*a*) $\eta=1-E_1^2$

(*b*) $\eta=3/2-\frac{1}{2}\sqrt{(1+4E_1^2)}$

and, in the case of a screw of constant pitch of maximum efficiency,

$$\eta=1-2E_1^2.$$

Fig. 59 gives a graph of the two limiting curves (*a*) and (*b*), and also the curve (*c*), calculated according to experimental results obtained by Captain Dorand in 1912.

Fig. 60 represents the curves giving, for six screws, thrust Q in function of the number n of revolutions in unit time for three stream velocities ($V=3$ m./s., 4.5 m./s., 6 m./s.).

The diameter of these screws was 30 cm. and their pitch ratio $h/d=0.75$. The two faces of the blades of these screws, the section of which is given on Fig. 39, were symmetrical.

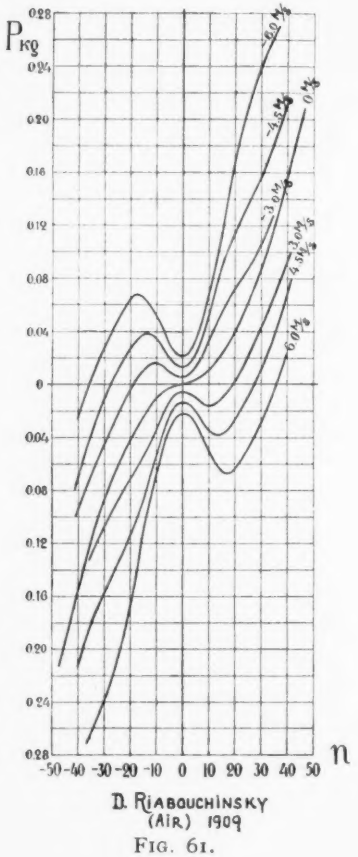


FIG. 61.

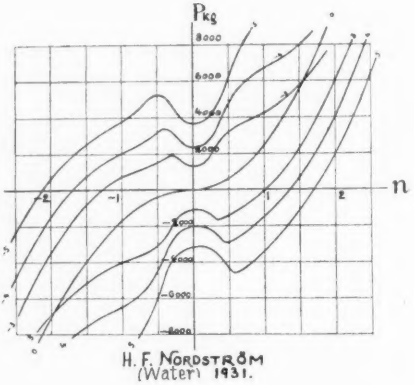


FIG. 62.

As already mentioned, flat sectors are considered as screws of zero pitch. It has been found experimentally that, for screws of zero pitch, in the vicinity of the point of inflexion of the torque curve (see Fig. 46), the torque coefficient $P/\rho V^2 S$ is proportionate to the number nd/V and that the value of the coefficient of proportionality is independent of the central angle γ of the blades. On Figs. 60, 61, 62, thrust is also expressed by P.

The curves shown on Fig. 60 permitted one to judge, probably for the first time, of the functioning of a screw in all cases which may possibly occur; in

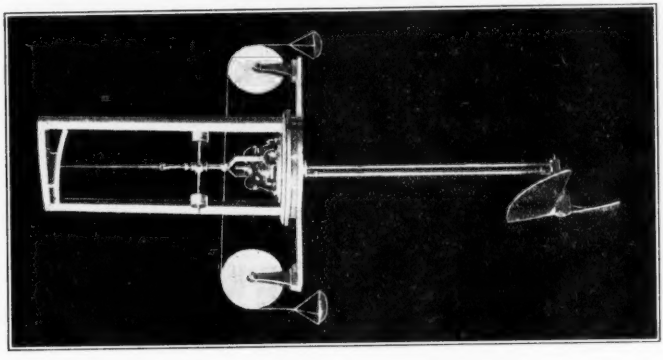


FIG. 65.

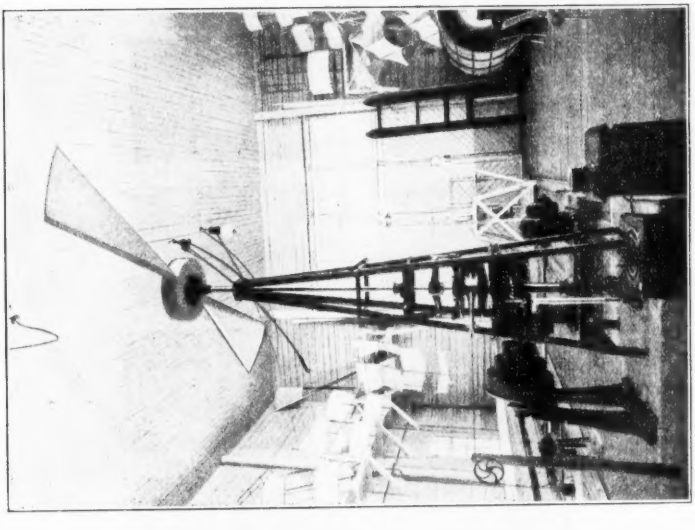


FIG. 64.

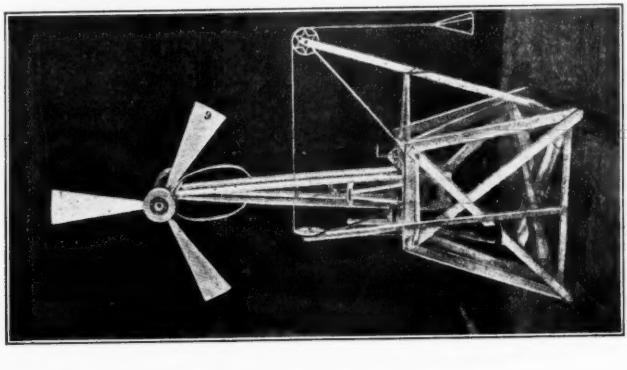


FIG. 63.

quadrant $(+n, +P)$ the screw acts as a propeller, in quadrant $(+n, -P)$ as a windmill or as an autogiro, and in quadrant $(-n, -P)$ as a brake.

Fig. 61 represents results of researches made with a screw of pitch ratio $h/d=0.75$ for three wind speeds ($v=3$ m./s., 4.5 m./s., 6 m./s.).

Fig. 62 represents results, attained by Mr. H. F. Nordstrom,* calculated for a screw revolving in water ($d=2.8$ m., $h/d=1$) according to data obtained with a model in the Stockholm Froude's tank.

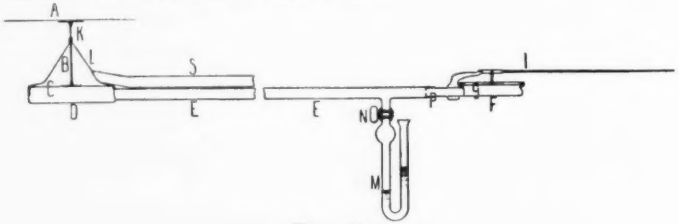


FIG. 66.

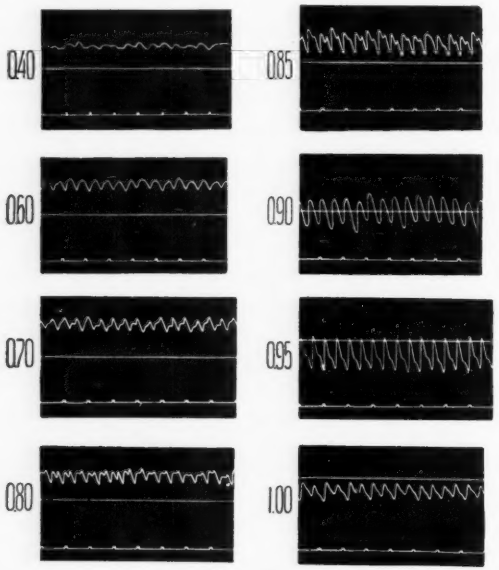


FIG. 67.

The two sides of the screws used by Mr. Nordstrom were not symmetrical and their shape noticeably differed from the shape of the screws used by the author, but the characteristic features of the curves obtained in air appear again in Mr. Nordstrom's curves.

Figs. 63 and 64 represent apparata used to study screws working at fixed point and Fig. 65 to study propelling screws in the wind tunnel. Colonel C. Renard's method, viz., that of direct measurement of the reaction exerted on the casing of the electro-motor was applied in the apparata shown on Fig. 63 and Fig. 65.

* "A Study on the Interaction between the Engine, the Screw-Propeller and the Ship" (Central Tryckeriet, Stockholm, 1931).

Fig. 66 represents an apparatus for studying pulsations in the slipstream of the screw; Fig. 67 represents the curves recorded by this apparatus.

The problem of the functioning of a screw, the axis of which is inclined towards the relative stream, has also been studied. Figs. 68, 69, 70 and 71 represent apparata which were used to study screws, the axes of which are orthogonal to the stream. The use of small elongated cylindrical electro-motors proved very practical. Those apparata allowed one to measure the thrust, drag and torque, and also the pitching and rolling moments of a lifting screw in side wind.

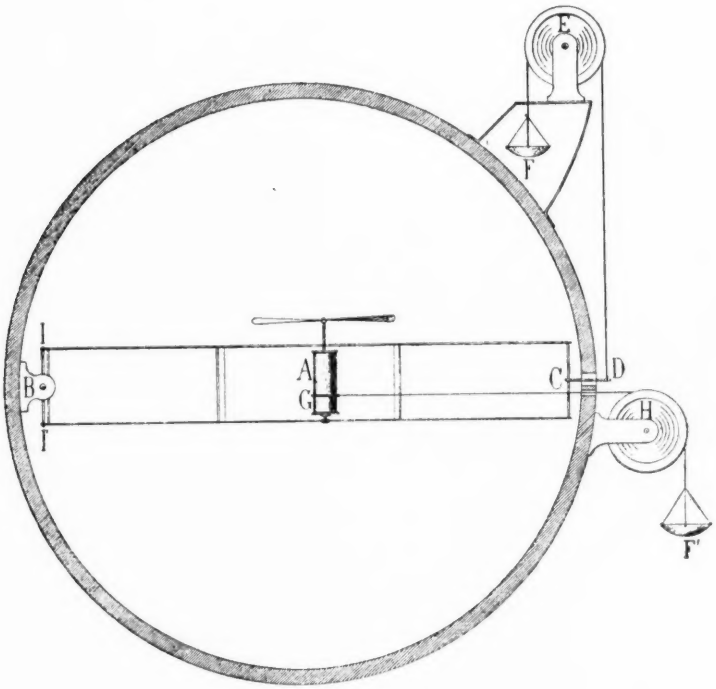


FIG. 68.

Several examples of the application of formulæ mentioned in this section were given in the second Bulletin of Koutchino—in planning aeroplanes, comparing aeroplanes to helicopters, helicopters with vertical axes to those with inclined axes, and airships to aeroplanes.

Fig. 72 allows one, for instance, to compare a Zeppelin airship with the Wrights' aeroplane (the calculations were made in 1908).

The graph on Fig. 72 corresponds to the case when the given weight Q can be transported at a given speed V, either by airship or aeroplane, with the same outlay of power, provided the area of the screw propeller's discs is equal in both cases. In order to make this comparison, it is necessary to exclude from the equations area S of the aeroplane wings and the volume O of the airship; for this the drag of the airship must be ascribed, not to the medial section, but to the power 2/3 of volume O.

The author also endeavoured to give a classification of lifting and propelling engines and describes several experiments with engines different from airscrews.

5. *Rotating Plates and Cylinders (Rotors)*

It is interesting to recall that Clerk Maxwell discussed the problem of a falling and autorotating rectangle of cardboard and noticed the force at right angle to the direction of the relative wind in 1853, that is to say, nearly at the same time when Magnus studied circular cylinders rotating in a stream.

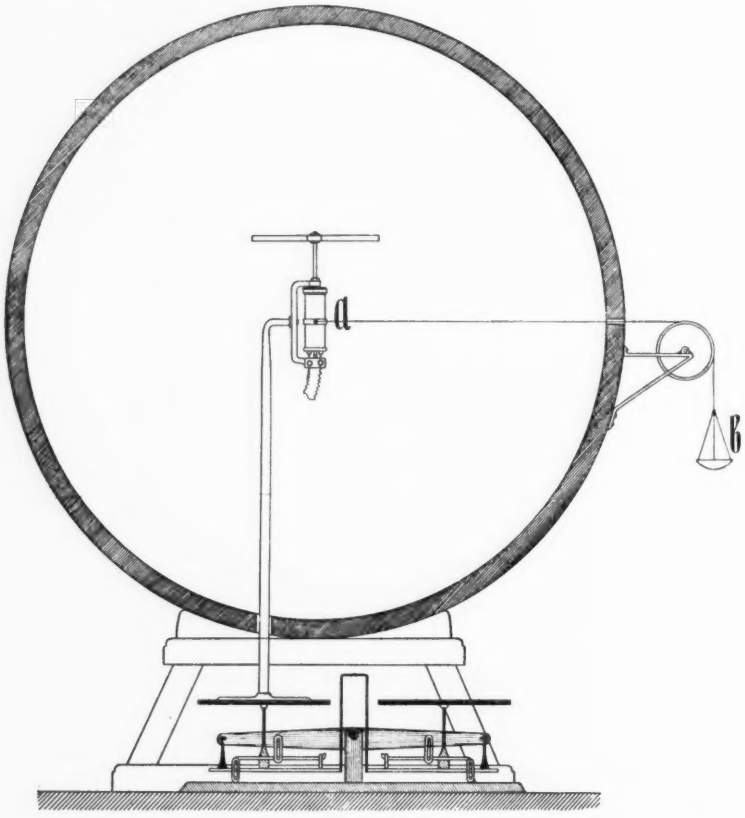


FIG. 69.

Since then and up to the present time, the study of the two phenomena has developed in a parallel way; it was either the phenomenon of Magnus which opened the way, or that of Maxwell. The first is determined by frictional forces, the second by the " leading edge effect "—they are therefore very different, but the fact that in both cases we have rotating cylinders and a force orthogonal to the relative stream brings them close together.

Maxwell's explanation of the autorotation of rectangles and of the force which compels these to follow in their fall a straight line trajectory forming an angle of approximately 45° to the vertical, can be summed up as follows :—

Supposing that the autorotating lamina A (Fig. 73) falls vertically. When the lamina occupies the position a the drag resistance is much less than when it assumes the position c. It results therefrom that when the lamina arrives at the position b the relative wind V_1, and consequently the resulting force R, are greater than the relative wind V_2 and the resulting force R, in position d.

On examining Fig. 73, one easily sees that in these conditions the lamina could effectively continue to rotate, and that the average resulting force acting

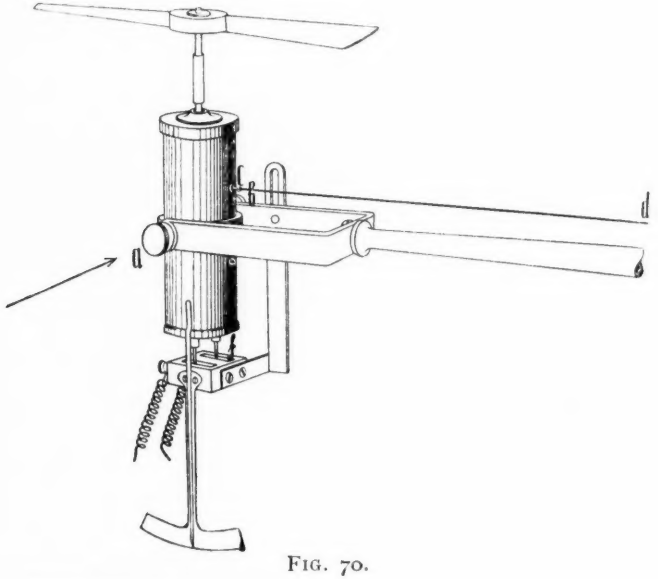


FIG. 70.

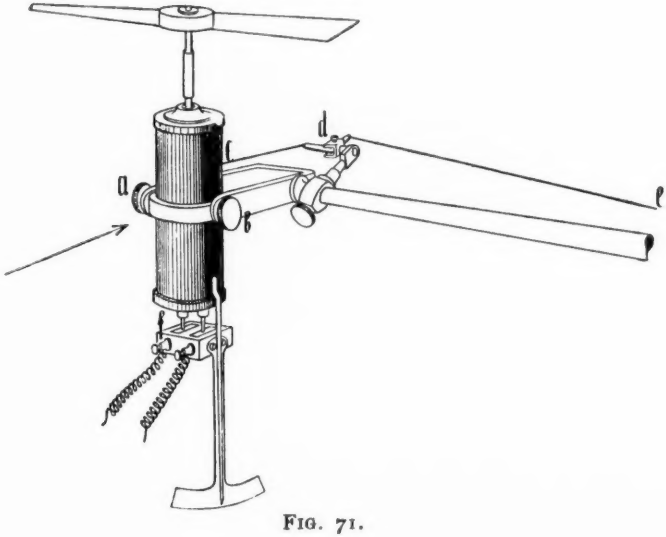


FIG. 71.

on the lamina when undergoing complete rotation, must influence the fall of the lamina towards the left.

It can be objected to this explanation that autorotation around an axis orthogonal to the relative wind persists even in the regular stream of a wind tunnel.

The author considers that the phenomenon investigated by Maxwell can be explained in the following way:—

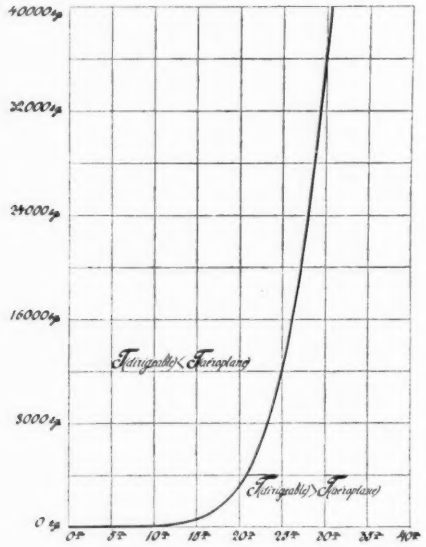


FIG. 72.

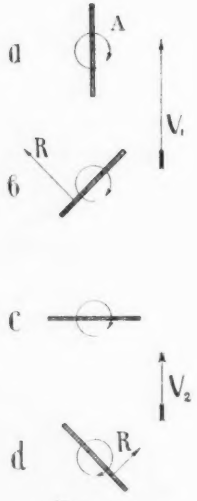


FIG. 73.

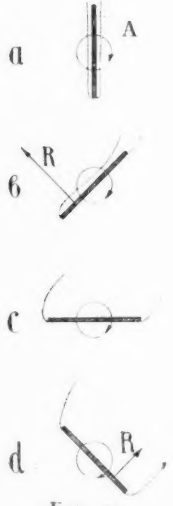


FIG. 74.

When the lamina A (Fig. 74), after having occupied position a, takes the position b, the curvature of streamlines of the relative motion and, consequently, the suction effect in the vicinity of the leading edge, driven by the wind, are stronger than when the lamina A takes the position d after having passed through the position c. A consequence of this explanation is the following :—

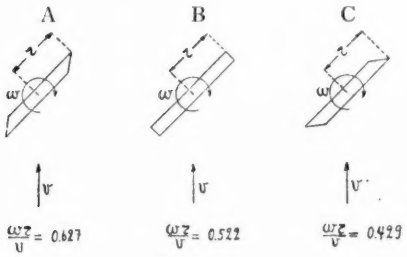


FIG. 75.

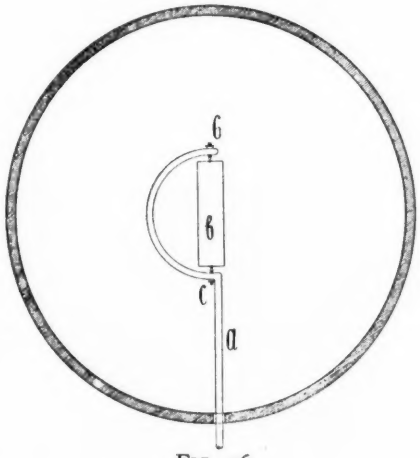


FIG. 76.

In order to increase the speed of autorotation it is necessary to accentuate the suction effect behind the edge driven by the wind, for instance, by cutting its edge at an angle. In accordance with this consideration the three plates A, B, C, the section and rotation direction of which in respect of the stream velocity are indicated on Fig. 75, must rotate at different speeds. Plate A must rotate at higher speed than plate B, and plate B faster than plate C.

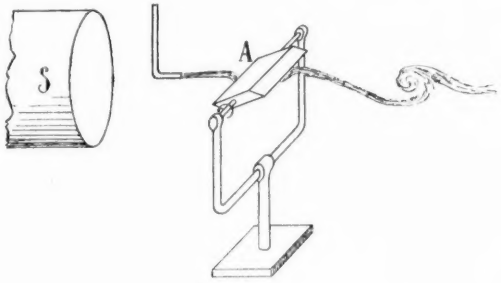


FIG. 77.

Fig. 76 shows the arrangement used for the study of autorotation of those plates in the wind tunnel.

The autorotation coefficients, *i.e.*, the ratio of the edge velocity $u = \omega R$ to the stream velocity v, of plates A, B, C, were found to be respectively 0.627, 0.522, 0.729. The leading edge effect shows itself again.

In autorotation of this type, *i.e.*, around an axis orthogonal to the relative stream, one has always $\omega R/V < 1$.

To avoid returning to this question later, we now give on Fig. 78 photographs of smoke filament lines in the neighbourhood of a plate set in autorotation in an airstream. The arrangement used is shown on Fig. 77.

These photographs (see Fig. 78), obtained in 1930 in collaboration with Mr. A. Séguin, concord with the author's explanation of this phenomenon.

In 1901 Köppen described the model of a flying machine which had to be sustained in the air by means of a plane autorotating around its longitudinal axis.

In the classification of different types of lifting and propelling engines, mentioned in the preceding section, the author considered, among others, the class of rotors (girouettes), including the general case of any angular velocity of a rotating body, and not only the case of autorotation.

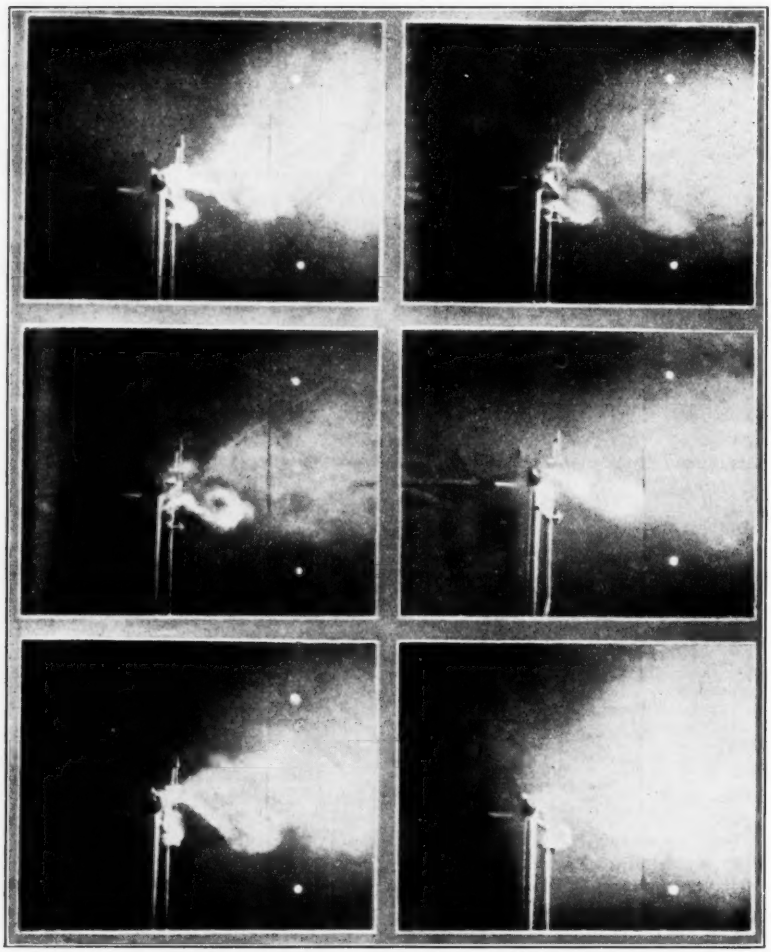
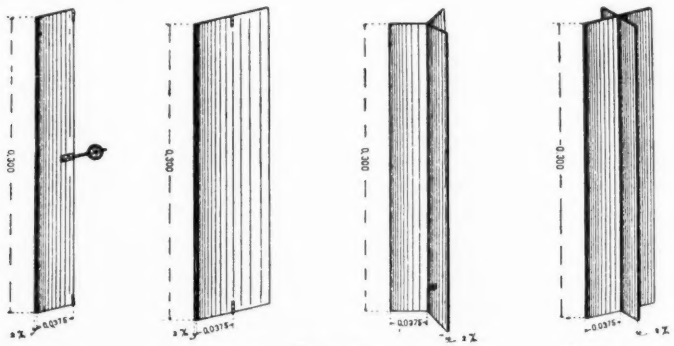


FIG. 78.

To give some idea of the aerodynamic properties of rotating bodies in a relative stream, tests were undertaken with one-, two- and four-bladed rotors shown on Fig. 79 (the three-bladed rotor was used for autorotation only).



a

FIG. 79.

The single-winged rotor (Fig. 79*a*) cannot be set in autorotation.

On Fig. 80 lift and drag coefficients determined for those rotors are plotted against the non-dimensional variable NR/V. This figure is taken from the third issue of the " Bulletin de l'Institut Aerodynamique de Koutchino " (Dec., 1909, p. 34). The symbols used in Fig. 80 have the following meanings:—

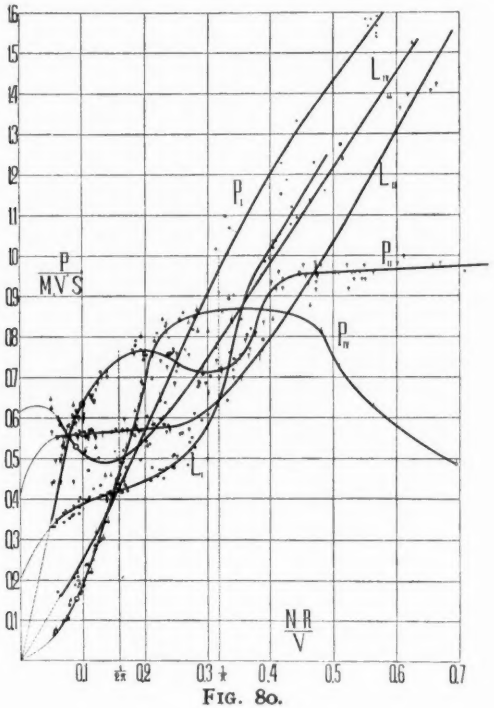


FIG. 80.

M is the density, N the number of revolutions in unit time, R the radius of the rotor (the width of one of the blades). The area S has the same value for the three rotors ($S=2Rh$, where h is the length of the blades).

The curves marked P_I, P_{II} and P_{III}, give the variation of the lift coefficients and those marked L_I, L_{II} and L_{III} of the drag coefficients of each of the one-, two- and four-bladed rotors.

The single-wing rotor (Fig. 79*a*) gave the highest lifting force.

An interesting characteristic of these curves is that the abscissa of the maxima, minima and points of inflexion appear to be multiples of $\omega R/V$.

In 1912, M. A. Lafay, referring to the author's investigations, published researches upon rotors having the shape of circular cylinders. He ascertanied that the torque power necessary to drive the rotor in a relative stream is not sensibly greater and can even in certain cases be less than without wind.

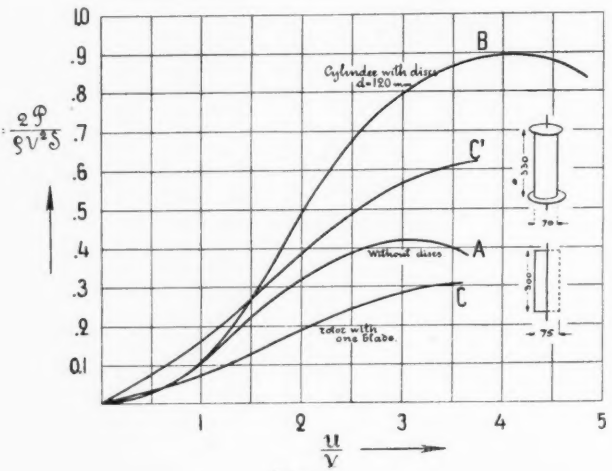


FIG. 81.

In Fig. 81 are compared the author's experiments on a single-winged rotor (1909) and the Ackeret experiments (1924) with circular cylinders, with and without protecting discs.

The curves show the relation between the lift coefficient and the ratio $u:v$ ($u=2\pi nR$). The curves c and c' correspond to the same single-winged rotor without end discs, except that in curve c' the lift coefficient is based on the area of the wing and in curve c on the projected area of the circular cylinder described by the rotating wing.

6. *Aerodynamic Spectres (Flow Patterns)*

A method of visualisation of fluid movement in the vicinity of rigid boundaries has already been dealt with; we shall expound it now in greater detail. As already explained, a horizontal plate in the form of a piece of sheet iron A (Fig. 22), covered with black paper sprinkled with lycopodium powder, is fixed in the centre of the wind tunnel. The model, a flow pattern for which is wanted, for instance the two blades B and C (on Fig. 22), is placed on the plate, and when the wind begins to blow in the tunnel, the powder is blown off at points where speed or turbulence are at maximum and the black paper reappears.

Lycopodium flow patterns of a square lamina orthogonal (*a*) and oblique (*b*) to the stream are shown on Fig. 82.

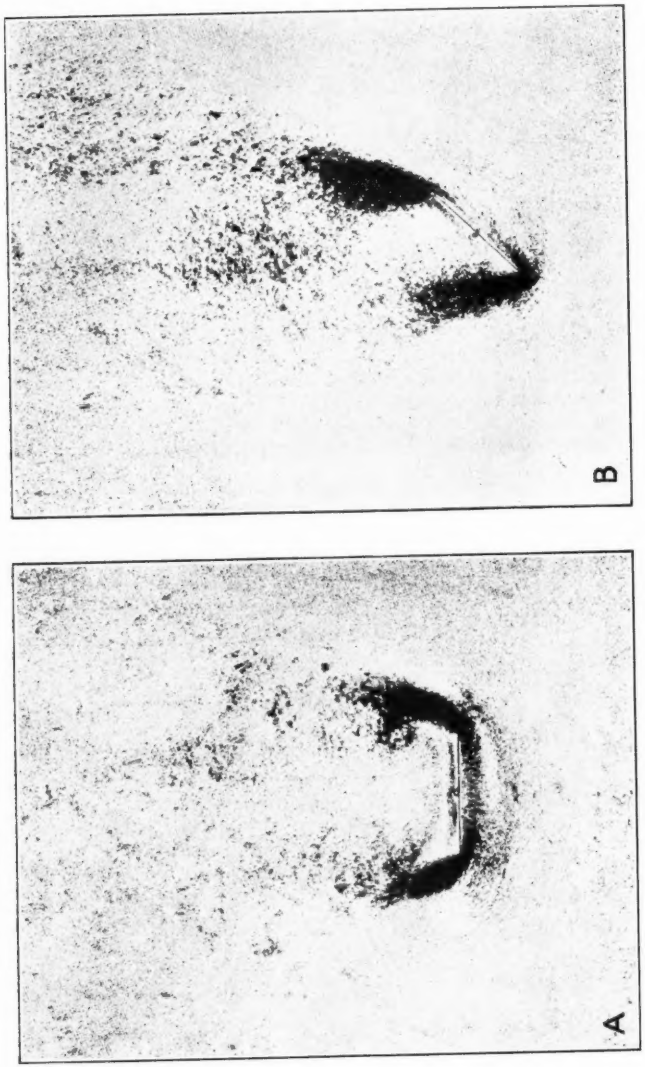


FIG. 82.

The flow patterns obtained in this way are similar to the snow formations in front of an obstacle, and, in fact, originally the author tried to reproduce these formations in the wind tunnel. The way in which the lycopodium is swept away by eddies at different points of the plate behind the obstacle, is rather curious to observe. It would be worth cinematographing and examining it at reduced speeds.

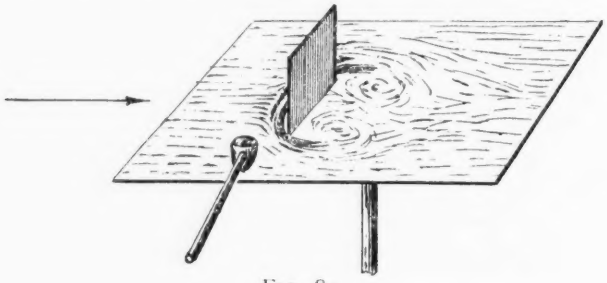


FIG. 83.

This study brought the author to another curious phenomenon. If at the moment when the wind begins to carry up the fine powder, one taps only once on the edge of the horizontal plate with a small hammer (Fig. 83), the streamlines of the motion and other details are at once traced by the powder, as can be seen on Fig. 84.

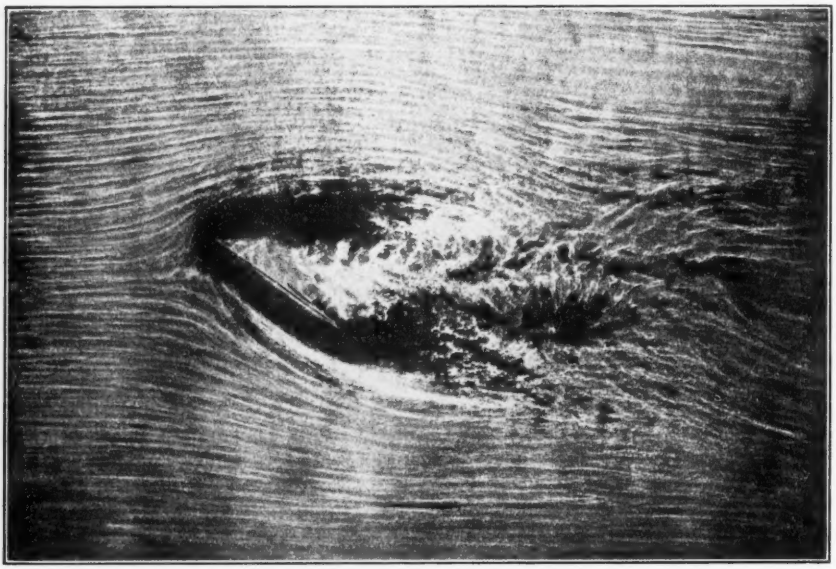


FIG. 84.

This figure should be compared with Fig. 82 *B*, obtained without knocking the plate. The author considers that the streamlines so traced are produced by eddies (vortex tubes) which coincide with streamlines (stream-tubes). He has

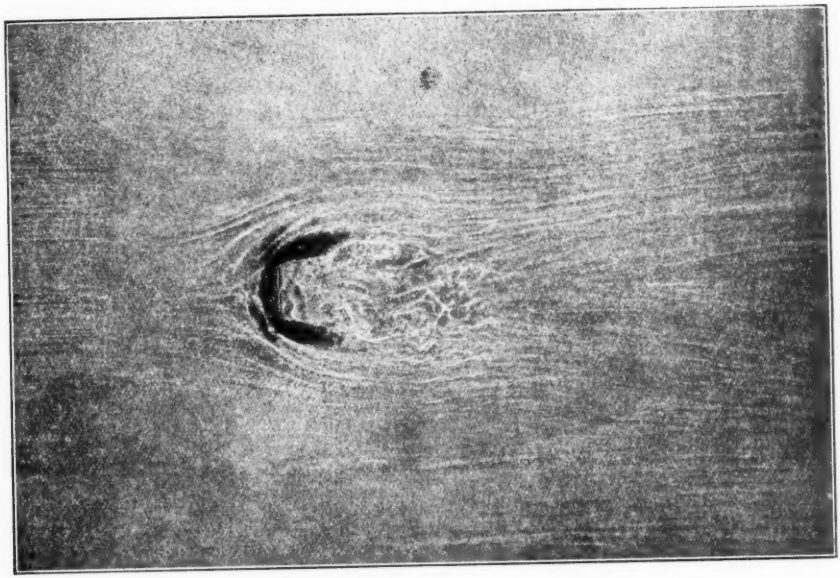


FIG. 85.

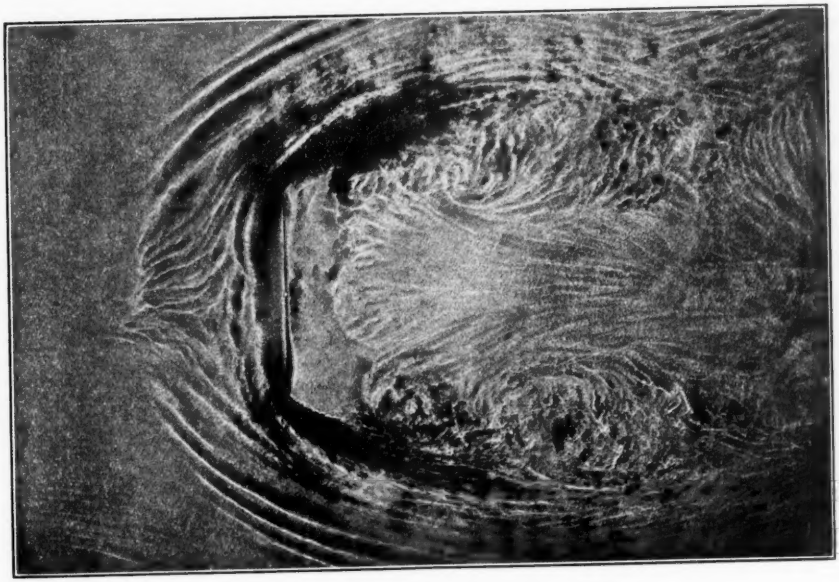


FIG. 85a.

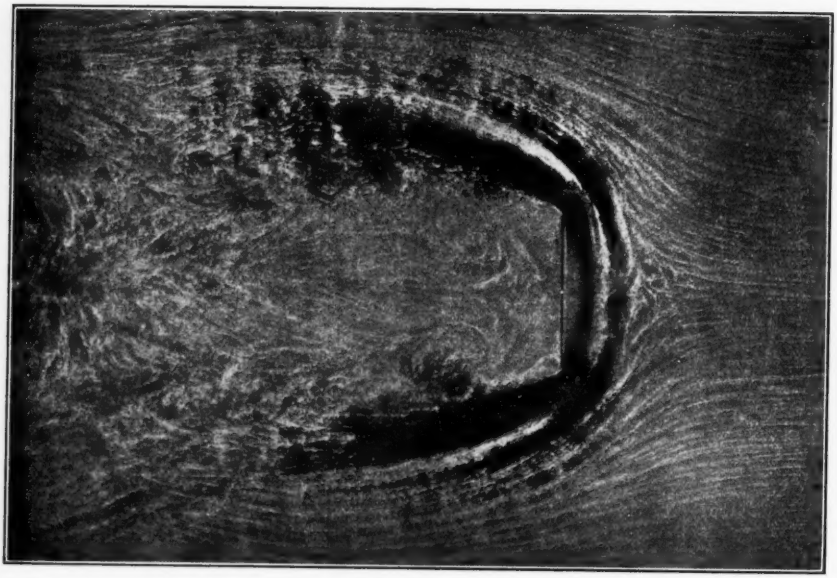


FIG. 86.

FIG. 86*a*.

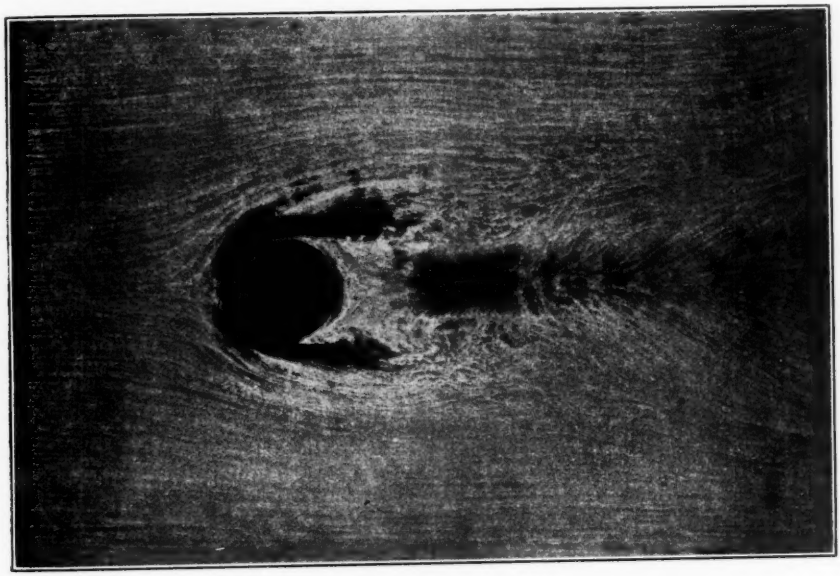


FIG. 87.

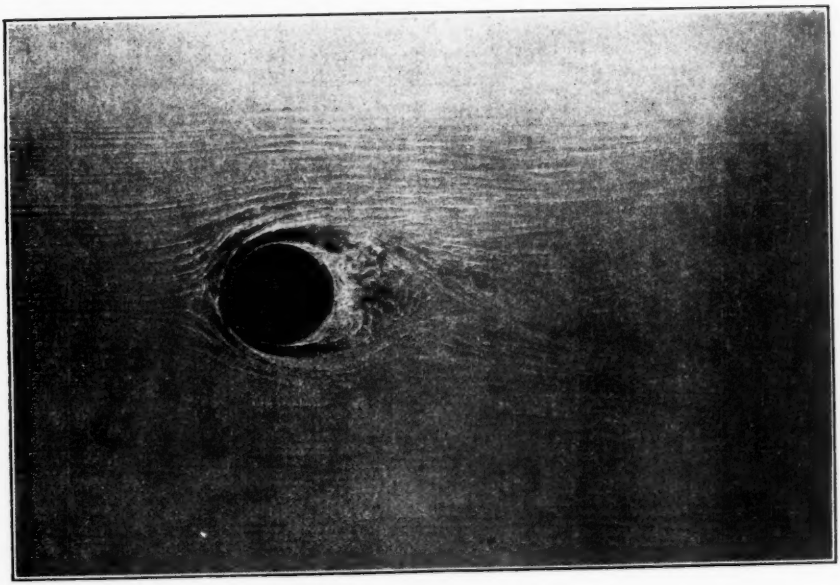


FIG. 87*a*.

emphasised on a number of occasions the importance of this method, which gives an idea of what is going on in the boundary layer.

The flow patterns shown on Figs. 85 and 85*a* correspond to two square lamina of different size (40 cm. × 40 cm. and 160 cm. × 160 cm.) and those shown on Figs. 86 and 86*a* correspond to a square lamina (120 cm. × 120 cm.), but the speed in the second pattern is twice as great as in the first one. The radius of the eddies which coincide with streamlines in the layer of horizontal plates, but not the

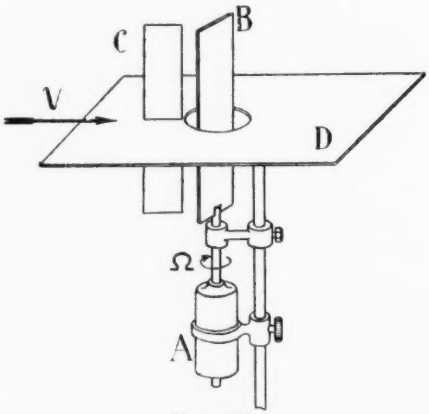


FIG. 88.

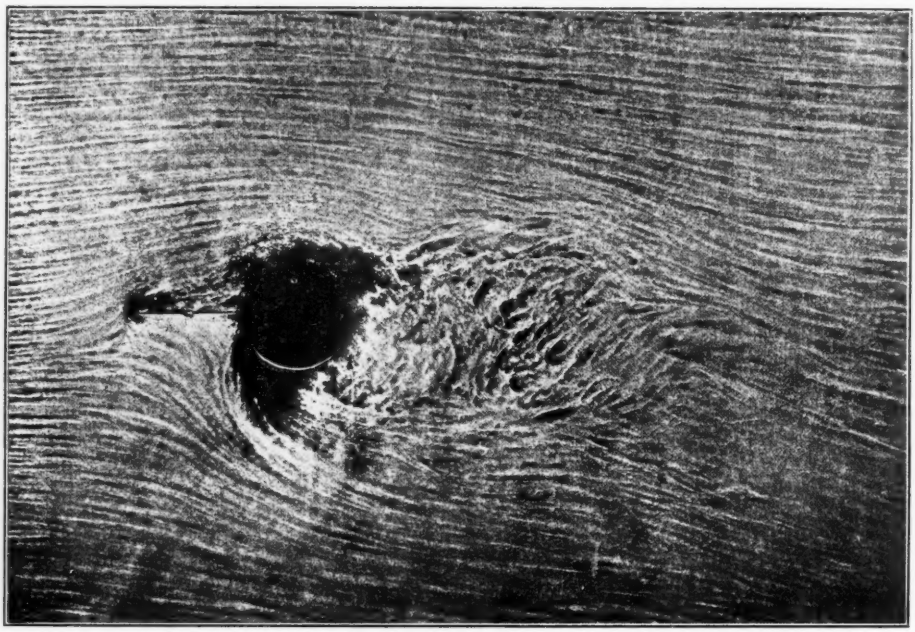


FIG. 89.

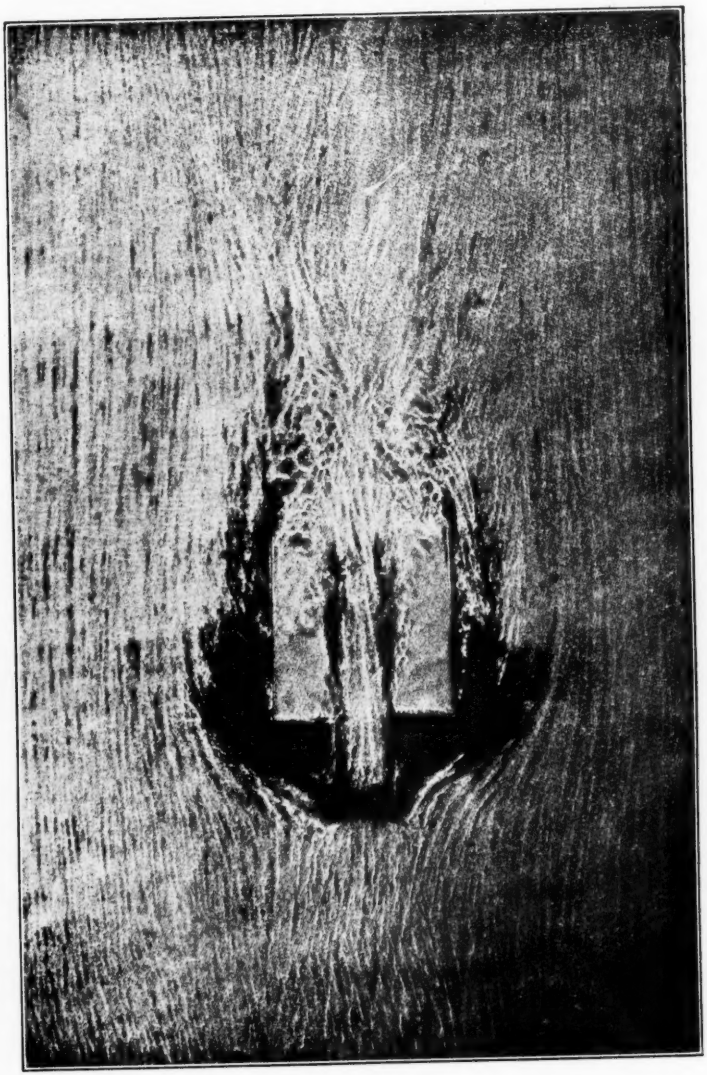


FIG. 90.

transversal eddies with free ends contiguous to the square laminæ, seems to diminish when the speed increases, whence this phenomenon seems to depend upon Reynolds number.

The pattern on Fig. 87 corresponds to a cylinder, the height and diameter of which are equal, and that on Fig. 87*a* to a hemisphere. The motion is considerably perturbed by the upper edge of the cylinder.

The pattern on Fig. 89 was obtained with the arrangement shown on Fig. 88.

The motor *A* drives rotor *B*, in front of the axis of which a plate *C* is placed parallel to the direction of the airflow *V*. The sense of rotation is indicated by an arrow.

The author would like to draw attention to the flow pattern shown on Fig. 90, which shows an interesting system of over-crossing lines in front of the obstacle.

A set of 54 different flow patterns obtained by this method is given in the " Bulletin de l'Institut Aerodynamique de Koutchino " (No. 3, December, 1909). The author named these flow pictures " aerodynamic spectres " in analogy to magnetic spectres. Somewhat similar imprints and movements can be observed when a wave, after breaking on the sand, ebbs back towards the sea.

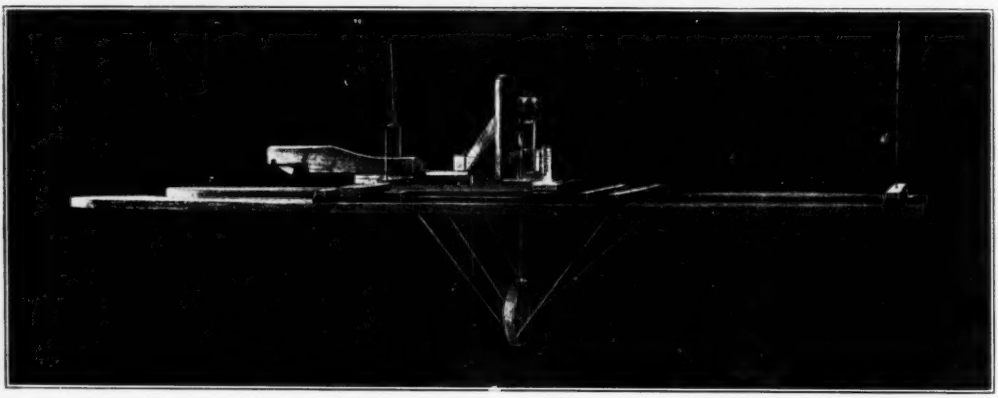


FIG. 91.

An interesting modification of this method with a view to obtaining flow pictures at high wind speeds is described in the papers of Higgins and Jacobs and Weick. The plate was painted with a mixture of lamp black and kerosene. Analogous experiments have also been recently made in water by Hinderks, in Germany, who utilised fresh oil colours, and by Winter in U.S.A. In Chapter IV an application of this method will be mentioned at velocities beyond the speed of sound.

In all these experiments the same remarkable striation appears on the lycopodium or on the colour layers.

7 *Solids Suddenly Set in Motion in a Liquid*

If a solid completely immersed in water is moved, the force producing acceleration is equivalent to the product of acceleration by the mass of the body increased by the " additive mass," owing to the presence of the fluid. For a sphere this additive mass is equal to one half of the mass of fluid displaced by the sphere. For a circular disc of radius c, the additive mass has the value $8\rho c^3/3$.

In the case of a sphere oscillating in a fluid, this theory is well confirmed by experiment, but the theory breaks down if the acceleration is sufficiently great.

It is not quite the same thing if the solid is accelerated in a fluid initially at rest, or if we set the whole fluid in accelerated motion whilst the solid is motionless; but the result must be the same if, instead of starting suddenly a solid in a fluid initially at rest, we stop abruptly a solid that moves with the uniform speed of a steady stream in which it is immersed.

Practically it is more convenient to stop a moving solid than to start it suddenly in motion.

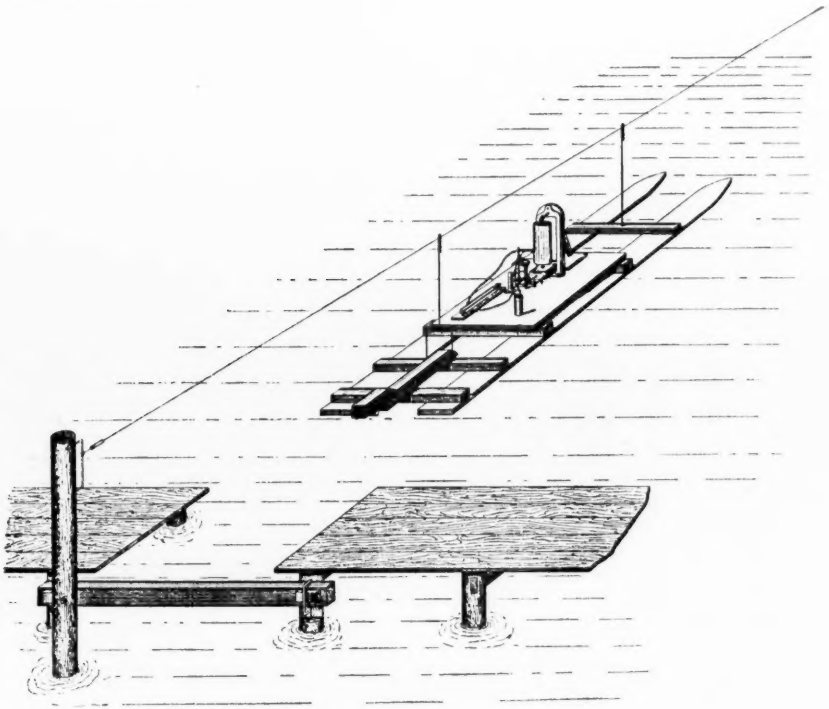


FIG. 92.

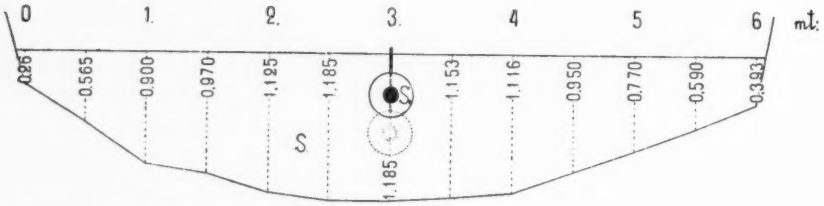
The author utilised this in the following experiment, carried on for the study of the reaction produced by sudden variation of the velocity of a solid immersed in a fluid.

The float shown on Fig. 91 was moving at the speed of a small stream, until it was abruptly stopped by a barrier (Fig. 92).

The section of the stream is given in Fig. 93.

The recording apparatus is shown in Fig. 94. This apparatus was fixed on the float in such way that its lower part was immersed in the water.

Discs of two sizes $D=12$ cm. and $D=36$ cm. were studied. The diameter of the rubber membrane, the deformation of which enabled us to record the pressure exerted upon the disc by the liquid, was 8 cm. for both discs. A complete description of this apparatus and of the way it was used is given in the " Bulletin de l'Institut Aérodynamique de Koutchino " (No. N3, pp. 5-19, Dec., 1909).



S=5.420 mt²
S=0,102 mt²

FIG. 93.

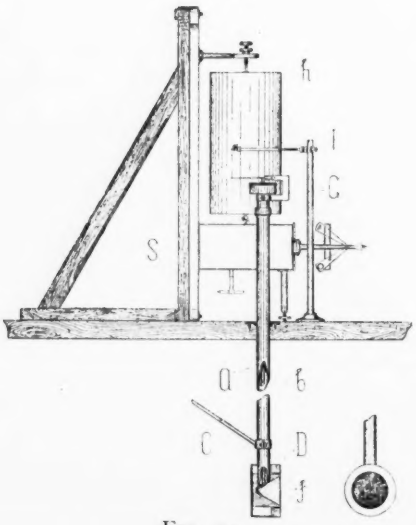


FIG. 94.

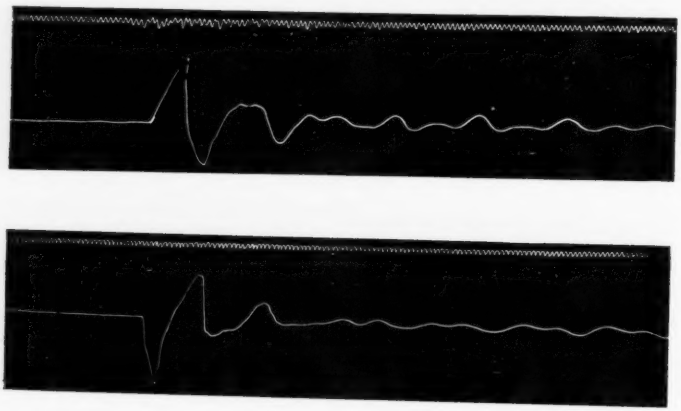


FIG. 95.

The two curves in Fig. 95 represent the variation of pressure on both sides of the immersed discs ($D=36$ cm.) which acquires suddenly the relative speed of 30 cm. per second.

Each period of the time curve is the hundredth part of a second.

It is interesting to notice in Fig. 95 how the sign of the pressure reverses and to compare this result with the description of an experiment with a moving body, stopped suddenly and directly afterwards released, as given by Osborne Reynolds in 1877 (One-vortex Motion, Scientific Papers, Vol. I, page 188); the released body still continues for a short distance in its original direction.

In the author's experiments the pressure law is expressed by the formula

$$2X_{\max}\, T / VS^{3/2}\rho = 3.09 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where $2X$ is the maximum resulting force exerted on both sides of the disc; T the time interval during which the pressure curve rises from zero, reaches its maximum value and drops back to zero; V the velocity of the relative stream; S the area of the disc; 3.09 a coefficient deduced from experiments.

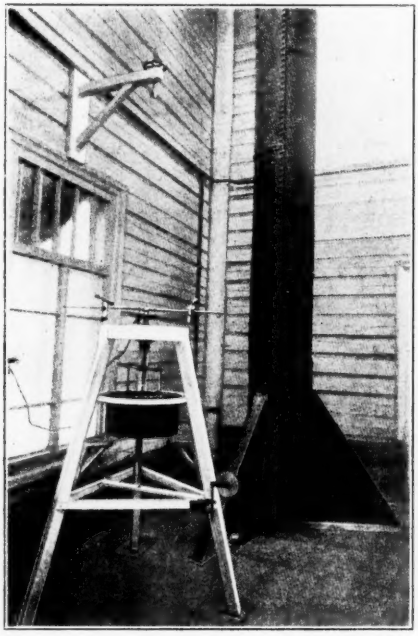


FIG. 96.

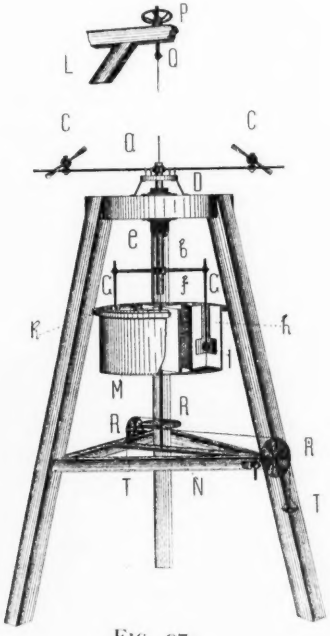


FIG. 97.

By admitting that the pressure curve can be replaced by a sine curve, we deduce from formula (1) an impulse four times stronger than that given by the generally admitted theory. This result may be explained as follows.

The impulse acting on a solid started in a perfect liquid can be compared to a shock of a perfectly soft body which rests in contact with the solid after the shock. If a cavitation is formed this comparison holds no more, and it seems more plausible to interpret the impulse acting on the solid started suddenly in a liquid as a shock of a more or less elastic body, which " rebounds " after the shock. The impulse exerted on the solid is then approximately twice greater.

The fact that the impulse recorded is, however, not twice but four times greater than the normal one, may be attributed to an increase of relative speed determined by elasticity of the barrier which stopped the float abruptly (Fig. 92).

8. *Remarks on Some Apparata*

Before closing this chapter we will note a few further apparata constructed within the period 1904-1909.

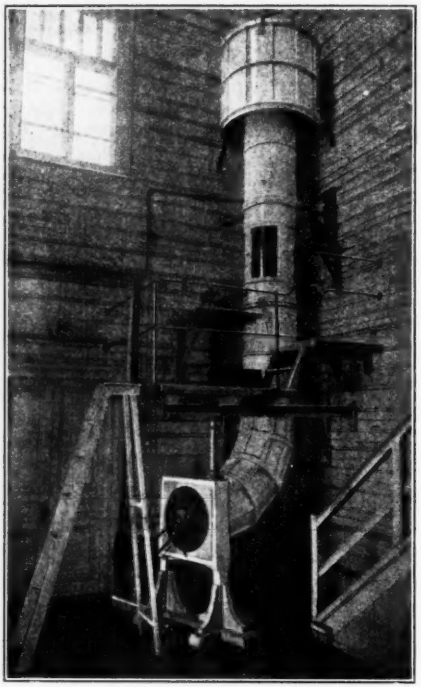


FIG. 98.

The large vertical cylinder shown on Fig. 96 was constructed for research on resistance of bodies falling freely in compressed or rarefied gases. In some cases an initial speed was given the falling body.

The cylinder was 8 metres high, 60 cm. in diameter, with walls 12 mm. thick. The compressor gave a pressure of 10 kilos. This was the first step towards compressed or rarefied air tunnels. This apparatus was also used for research on the resistance of liquids of different viscosity or submitted to different pressures. Later, this apparatus was used as a reservoir for compressed air for research in a gaseous stream at high speeds.

The second apparatus seen on Fig. 96 and a detailed design of which is given in Fig. 97, was used for research on the influence exerted upon the resistance of bodies by different arrangements to amortise the movements generated in the liquid contained in the cylinder M by the circular motion of the bodies I. The resistance of the bodies I was estimated by measuring the reaction exerted upon M which was suspended to a steel wire. In order to alter the speed and the rotation sense of the hollow axis b and, consequently, those of bodies I, the

electromotors *CC* (Fig. 97) which drew the small screw propellers communicating to the hollow axis *b* its rotation, could be fixed at the distance from the axis and in the position required.

Fig. 98 shows a small vertical wind tunnel. This tunnel was used principally with a torsion balance for research on windmills.

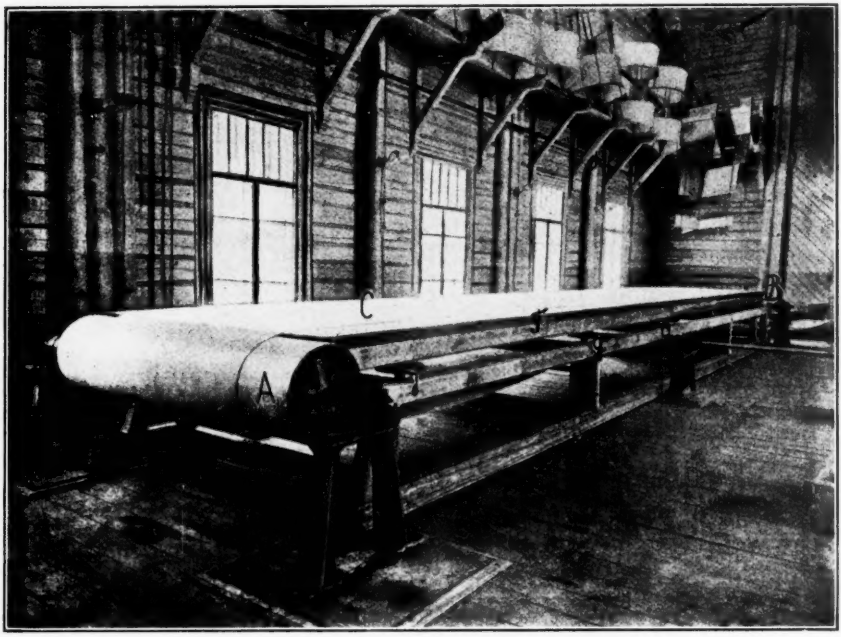


FIG. 99.

The last apparatus to be mentioned in this section, shown in Fig. 99, was used to estimate frictional resistance.

An endless belt moving round rotating cylinders *a* and *b* carries with it a certain quantity of air between the fixed surfaces *c* and *d* (Fig. 100). After determining the speed distribution of the air swept off by the belt, through the cross section at *gf*, the frictional resistance acting on the belt between *ee* and *gf* was estimated by the momentum carried by the fluid.

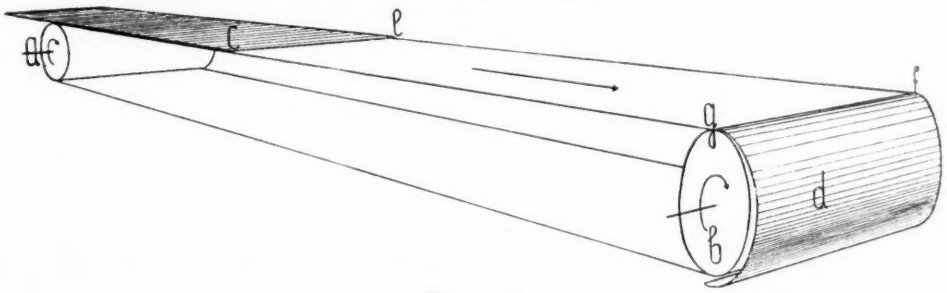


FIG. 100.

The author realised at the time the importance of studying velocity distribution to establish a rational theory of turbulent flow.

The first description of the apparatus shown on Fig. 99 was published in 1908; the first small-sized model was tested in 1905.

In the same paper, the author mentioned that when the belt rolls round an axis, even of very small diameter (for instance 3 cm.), the rate and distribution of velocities in front of and behind the axis is not noticeably modified (Fig. 101).

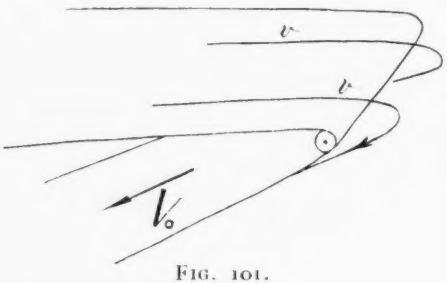


FIG. 101.

The apparatus shown on Fig. 99 was also used for researches carried on in the second period (1910-1914).

CHAPTER III.

RESEARCHES CARRIED OUT IN THE PERIOD 1910–1918

9. *Comparative Researches on Wind Tunnels*

Since 1910 considerable discrepancies between results obtained in different laboratories became manifest. Notwithstanding its apparent simplicity, the study of pressure exerted by a stream on a plate at different angles of incidence in a wind tunnel led to very contradictory results. Mallock in England, Rateau in France and Föppl in Germany, had found that between 30° and 40° the pressure could have two different values for the same angle of incidence. Eiffel in France and the author in Russia found, on the contrary, a continuous curve.

In order to elucidate the causes of such discrepancies, the author constructed at Koutchino, first, a wind tunnel with free air stream, shown in Fig. 102; second, a small Prandtl's wind tunnel with closed circuit, which at that time was not open in the centre (Fig. 103); and third, a small Eiffel tunnel to which the author added a conical diffuser with a wooden screw as a ventilator placed at the broad end (Fig. 104). This was a novelty, as in 1910 the Eiffel wind tunnel, which at that time was still at the Champs de Mars, had no diffuser.

Owing to a misunderstanding the diffuser was delivered with a cone angle considerably wider than ordered by the author. The construction of this diffuser having taken a considerable time, the author decided, nevertheless, to carry out his researches on Eiffel's wind tunnel, utilising the diffuser as it was, and published these researches in the " Technique Aéronautique " of December 15th, 1910, under the title " Étude sur le tunnel de M. Eiffel." In the " Technique Aéronautique " of January 15th, 1911, a reply by M. Eiffel was published, entitled " A propos d'une étude de M. Riabouchinsky," in which he discussed the experiments, but without alluding to the author's idea of using a diffuser. The wind tunnel with a more correctly drawn diffuser, shown on Fig. 105, is borrowed from Eiffel's patent, applied for in Paris, November 22nd, 1911, and delivered on February 5th, 1912.

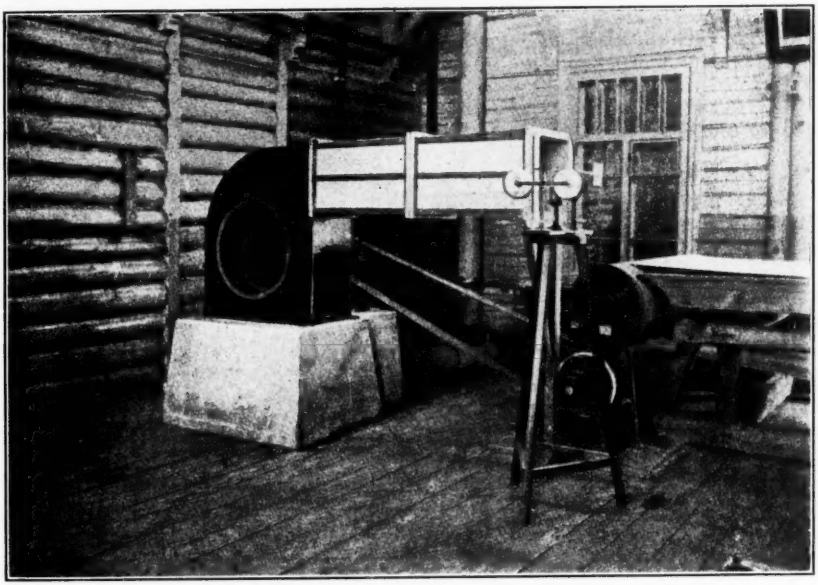


FIG. 102.

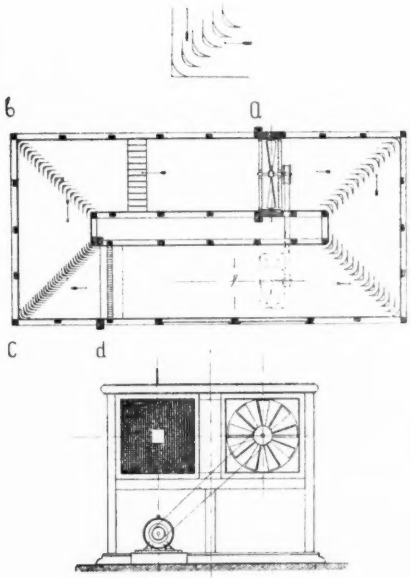


FIG. 103.

Let us now return to the discrepancies obtained in wind tunnels of different types mentioned above. In order to find an explanation of these differences, the author adopted the standpoint that it was necessary to study carefully the influence of conditions of experience which were regarded at the time as secondary. He ascertained the following :—

1. Resistance increases in wind tunnels limited by walls and diminishes in free jet tunnels. The explanation must be sought in the increase or decrease of

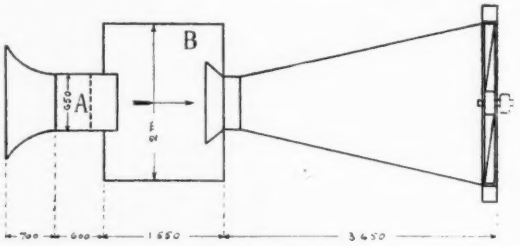


FIG. 104.

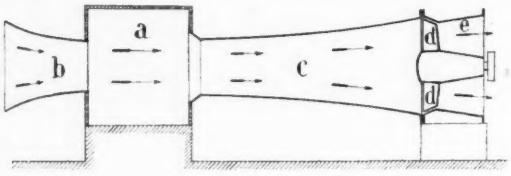


FIG. 105.

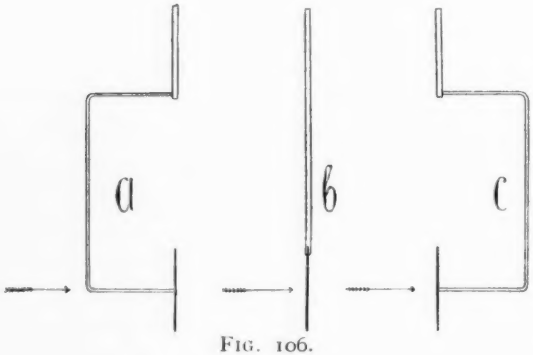


FIG. 106.

velocities on the surfaces of discontinuity in the vicinity of the edges due to the contraction or the widening of the stream, according to the latter being or not being limited by walls.

2. Slight modifications introduced in the shape of the obstacle may cause a considerable modification of the resistance. By utilising the three methods for supporting a square plate in the stream shown in Fig. 106 at *a*, *b* and *c*, the author obtained in his wind tunnel (Fig. 8) the three curves represented on Fig. 107 and in the Prandtl tunnel (Fig. 108) the three curves represented on Fig. 108.

In the Koutchino tunnel the influence of the way in which the plate is held plays a less important part than in the Göttingen tunnel. Curve *b* in Fig. 108 shows that it is sufficient to fix the rod of support direct on to the edge of the plate (Fig. 106*b*) to lessen resistance by 25 per cent.

3. In the critical zone of change of type of flow (*régimes*) resistance is particularly sensitive to the degree of turbulence of the stream. Thus by eliminating

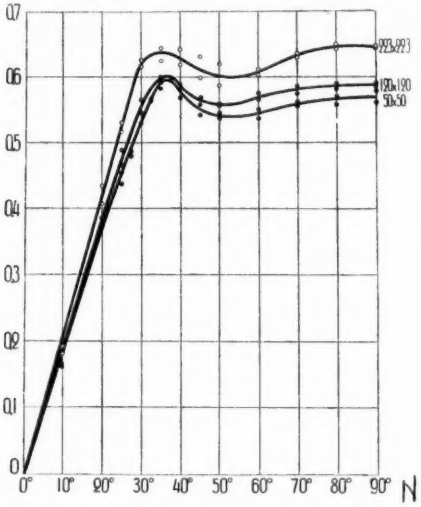


FIG. 107.

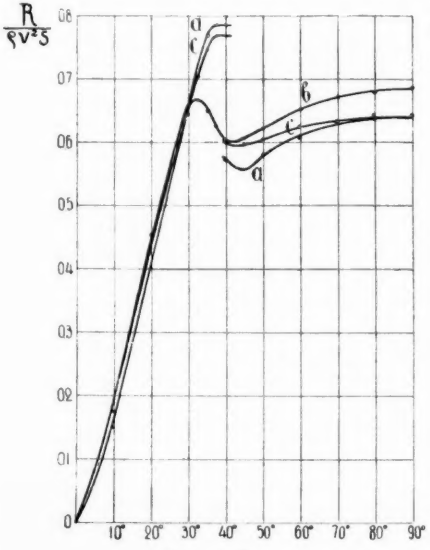


FIG. 108.

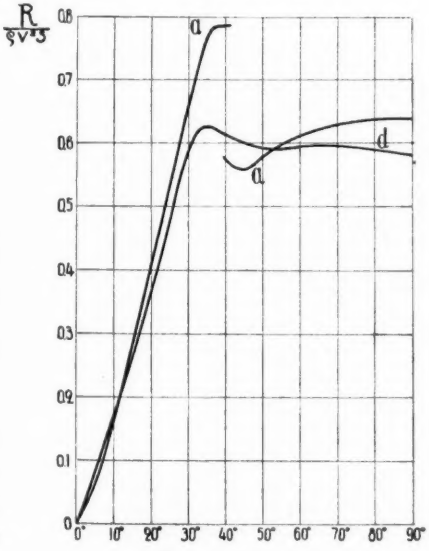


FIG. 109.

elbow $ABCD$ of the Prandtl tunnel (Fig. 103) so that the air was drawn directly from the hall into the tunnel, the author found that even when the plate is supported at its centre (Fig. 106*a*), the discontinuity disappears (Fig. 109*d*). An increase of the turbulence can therefore determine a noticeable decrease in the resistance.

This result, as well as the absence of discontinuity in the resistance curve obtained in the Koutchino tunnel (Fig. 107), were attributed by the author to a lesser turbulent fluctuation of the stream in the Göttingen closed-circuit tunnel. These results were published in the fourth " Bulletin de Koutchino " in 1912. They enabled the author to explain also the great divergency between results obtained by various authors who studied the resistance of spheres.

In Fig. 110, published in 1914, the author collected together the data on resistance of spheres known at that time.

In the article " Abriss der Lehre von der Flüssigkeits und Gasbewegung " (Handwörterbuch der Naturwissenschaften, Band IV, 1913) Prandtl mentions, in connection with discontinuity of resistance experienced by a thin plate near the critical angle, that " bei Turbulenter Bewegung bleibt die Erscheinung aus (Riabouchinsky)." Endeavours have been made since to apply this property of turbulence, by taking the sphere, to " measure " the relative intensity of turbulence. In 1914 Prandtl showed that it is possible to determine a decrease of the resistance of a sphere by fixing a wire hoop on its surface. This experience agrees with the results mentioned above under 2 and 3.

10. *The Method of Dimensionless Variables*

Lord Rayleigh, in England, and Vashy, in France, appear to have been the first to utilise the principle of dynamic similitude in the case where there is not only a single group of zero dimension, as in the case considered by Newton and Fourier, but two or several.

From the beginning of his researches, the author systematically applied the principle of dynamical similitude and in 1911 he published a paper entitled: " Méthode des variables de dimension zéro " (" L'Aérophile," 1 Septembre, 1911), in which some new developments and applications of this principle are examined. Additional researches were published in subsequent notes.

The author confined his attention to mechanic quantities. Dr. G. Buckingham (" Philosophical Magazine," November, 1921) further extended the author's theory to any arbitrary number of fundamental units. We adopt here Buckingham's notation.

Let us consider the equation

$$F(Q_1, Q_2, \ldots, Q_{n-3}, Q_{n-2}, Q_{n-1}, Q_n) = 0 \quad . \quad . \quad . \quad (1)$$

in which Q_1, Q_2, etc., are n physical quantities and F is an unknown function to be found by experiment. If we admit that the number of fundamental units is three and that, for instance, the quantities Q_{n-2}, Q_{n-1}, Q_n, are independent, *i.e.*, the dimensional determinant of these quantities is different from zero, we can transform equation (1) as follows:—

$$F(\pi_1, \pi_2, \ldots, \pi_{n-3}, 1, 1, 1) = 0 \quad . \quad . \quad . \quad . \quad (2)$$

or also, if we omit the three unities,

$$f(\pi_1, \pi_2, \ldots, \pi_{n-3}) = 0 \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$\pi_1, \pi_2, \ldots, \pi_{n-3}$, are dimensionless products of the form

$$\pi_i = Q_i Q_{n-2}^{ai} Q_{n-1}^{bi} Q_n^{ci} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

We might be led to ask: What do the curves that are obtained by plotting dimensionless products represent?

From a comparison of equations (1) and (2), we see that if $n = 5$, the curve obtained by plotting π_1, π_2, expresses the relation between Q_1 and Q_2, the values of Q_3, Q_4, Q_5, being equal to the unit in any system of measurement.

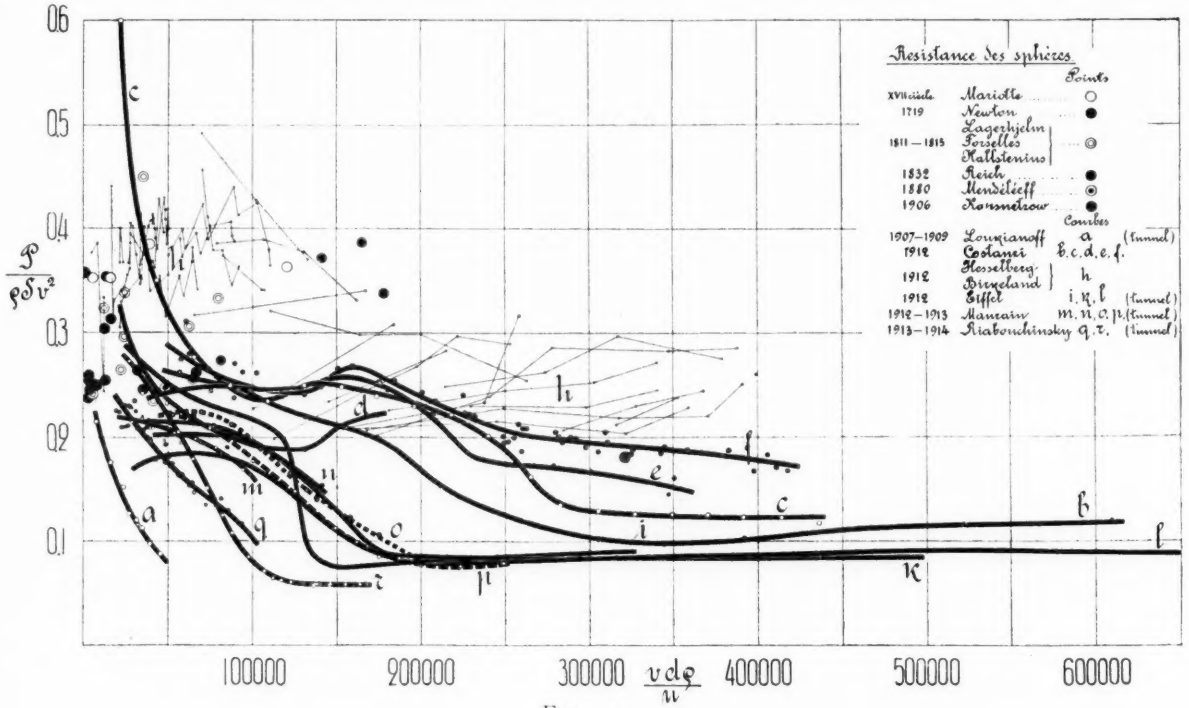

Résistance des sphères
Points
XVIIIème Mariotte
1719 Newton
1811–1815 Lagerhjelm, Forselles, Hallstenius
1832 Reich
1880 Mendelieff
1906 Kommetzow
Courbes
1907–1909 Lounianoff a (tunnel)
1912 Costanzi b.c.d.e.f.
1912 Hesselberg, Dirgeland h
1912 Eiffel i.k.l (tunnel)
1912–1913 Manzain m.n.o.p (tunnel)
1913–1914 Riabouchinsky q.r. (tunnel)
0.6
0.5
0.4
0.3
0.2
0.1
P / ρSv²
100000
200000
300000
400000
500000
600000
vdρ / w

FIG. 110.

To obtain between π_1, π_2, a relation corresponding to values C_3, C_4, C_5, of Q_3, Q_4, Q_5, we must transform equation (1) into the following:—

$$F(\alpha_1\pi,\ \alpha_2\pi_2,\ C_3,\ C_4,\ C_5)=0 \quad . \quad . \quad . \quad . \quad (5)$$

in which

$$\alpha_1=C_3^{-a_1}C_4^{-b_1}C_5^{-c_1},\ \alpha_2=C_3^{-a_2}C_4^{-b_2}C_5^{-c_2}.$$

Consequently, if we plot the products $\alpha_1\pi_1$, $\alpha_2\pi_2$, the curve so obtained can be interpreted as expressing the relation between the quantities Q_1, Q_2, the values of Q_3, Q_4, Q_5, being equal to C_3, C_4, C_5.

It is obvious from formulæ (2) and (4), that in order to determine the relation of dependence that exists between the quantities Q_1 and Q_2, we can change, instead of Q_2, the values of Q_3, Q_4, Q_5, only.

Let us consider an example; we suppose that

$$M=F(N_1R_1\rho_1\mu) \quad . \quad . \quad . \quad . \quad . \quad (6)$$

expresses a functional dependence between the moment M of frictional resistance about the axis of a rotating disc, the radius R and the number N of revolutions per unit time of the disc, the density ζ and the viscosity μ of the surrounding fluid. If we notice that any three of these four quantities can be considered as independent, we can transform equation (6) in four different ways:—

$$M\rho/\mu^2R=F(N\rho R^2/\mu,\ 1,\ 1,\ 1)$$
$$M\rho^{3/2}N^{\frac{1}{2}}/\mu^{5/2}=F(1,\ R\rho^{\frac{1}{2}}N^{\frac{1}{2}}/\mu^{\frac{1}{2}},\ 1,\ 1,\ 1)$$
$$M/\mu NR^3=F(1,\ 1,\ \rho NR^2/\mu,\ 1)$$
$$M/\rho N^2R^5=F(1,\ 1,\ 1,\ \mu/\rho NR^2)$$

The corresponding curves allow us to determine the functional dependence between M and N, R, ρ or μ beyond the range of values that the experiment means at our disposal could allow us to reach. Some of these curves are given in section 11.

The most important application of the dimensionless variables that can be considered as corollaries of the above-mentioned fundamental theorem, formulæ (2) or (5), are:—

1. In decreasing the number of independent variables this method considerably simplifies the graphical study of empirical dependence.
2. Since each of the variables represents a relation between several physical quantities, by varying one of these quantities making up the given variable, we can study the effect of varying any of the others.
3. If the law of dependence between two quantities found by this indirect process is not confirmed by the direct experimental investigation, it is necessary to infer that another factor is involved and this might lead to the discovery of this factor, the effect of which on the phenomenon might otherwise not have been suspected.
4. When the results of investigation depend upon chance and follow one another without any apparent order, this theory allows us to trace the most probable curve.
5. After having reduced the study of the relation between n physical quantities, determined by k fundamental units, to the study of a relation between $n-k$ dimensionless products of these quantities, we can try to express this relation by applying the usual methods of interpolation and of approximate representation of functions.

In the description of the Koutchino hydrodynamic laboratory (Fig. 12), published in 1912, the author mentioned that the kinematic viscosity for water at 15°C. being approximately one-twelfth as great as for air at the same temperature, each phenomenon observed in the air will occur in water at one-twelfth the speed at which it occurs in air. He added that this circumstance greatly facilitated the direct observation of the phenomenon.

This reasoning (as well as that which led, after the war, W. Margoulis, M. Munk and E. F. Relf to the variable density wind tunnel) is based upon the second corollary mentioned above, of the fundamental theorem of the theory of dynamical similitude. In fact, in order to study the influence of an increase of speed on the resisting force exerted by air upon a solid body, instead of increasing the velocity, we lessen the kinematic viscosity of the fluid by substituting water to air. We could also increase the dimensions of the solid body.

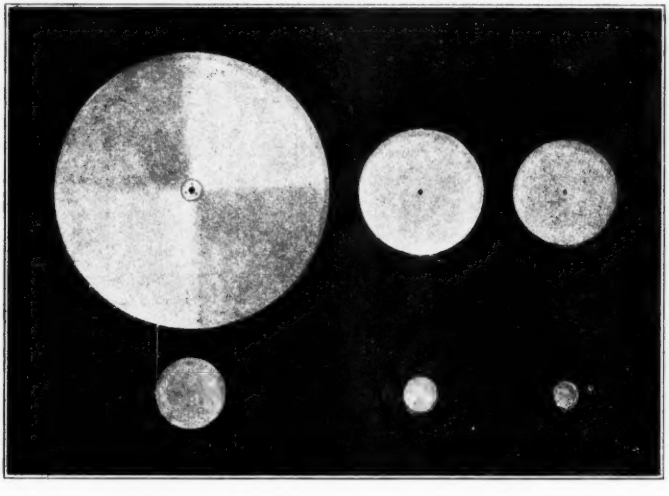


FIG. 111.

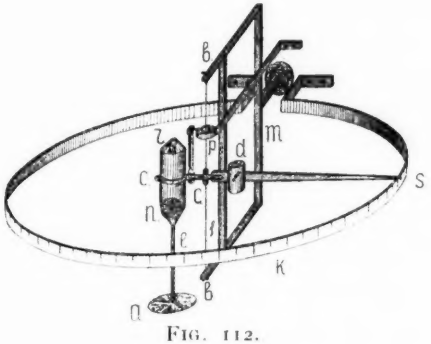


FIG. 112.

11. *Frictional Resistance of Rotating Discs*

Hagen and Reynolds discovered the passage from the Poisseuil régime to the turbulent régime in tubes; Couette observed a similar phenomenon between two cylinders. The author established in 1912, and published in 1914 (fifth " Bulletin de Koutchino "), that in the case of discs revolving in their own plane, a change of régime also took place, but that, in this case, one observed the passage of the law $V^{3/2}$ to the law of turbulent régime $V^{1.85}$. The author also

mentioned in this paper that one could expect in the case of the discs a second change of régime corresponding to the passage of the law V to the law $V^{3/2}$.

In Fig. 111 are shown the aluminium discs which were used. Their surfaces were well polished. The maximum and minimum diameters were 7 cm. and 79 cm. The torsion balances for the small, middle-sized and the large disc of 79 cm. are shown on Figs. 112, 113 and 114. For the middle-sized discs a bifilar suspension of the motor was used. The maximum speed at the circumference of the large disc was 80 metres per second.

The results of these experiments are shown in Fig. 115. The method of dimensionless variables is applied and it is seen how well the points obtained in air and in water with discs of six different sizes form a single curve. This curve

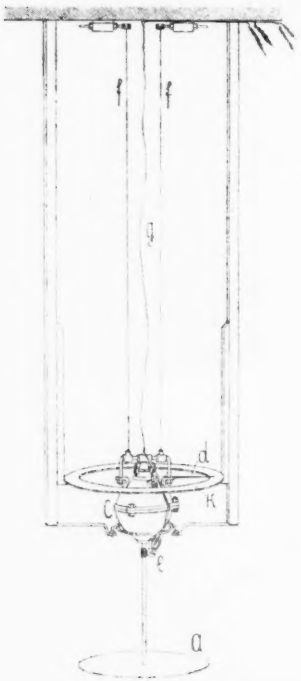


FIG. 113.

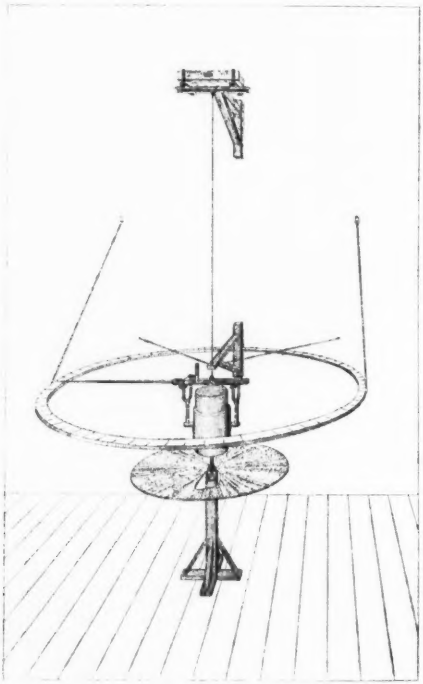


FIG. 114.

can be interpreted as expressing the functioning dependence between the skin friction moment M, exerted upon the disc by the surrounding fluid, and the viscosity μ of the latter. Examination of this curve shows that a decrease of the moment may correspond sometimes to an increase of viscosity. This curve shows also that in the case of discs we have, as in that of flow through a pipe, a critical speed when the laminar régime breaks down and the motion becomes turbulent. But, as we already mentioned, there is also a considerable difference between the two cases. In the experiment of Poisseuil and Reynolds with pipes, the resistance in the laminar régime is proportional to the first power of velocity and in the author's experiments with discs it is proportional to the three-halves power. The three-halves power of the velocity appears for the first time in a resistance formula of the form $aV + bV^{3/2} + cV^2$ used by Newton to express the

results which he obtained in studying the oscillation of a sphere suspended by a thread.

Allen found ("Phil. Mag.," Sept. and Nov., 1900) that, within certain limits of velocity V, the resistance R of small spheres is proportional to $V^{3/2}$. Lanchester ("Aerodynamics," 1907, p. 135) designates this law as "Allen's Law" and tries to demonstrate that it must be considered as the "normal law of external friction." The argument of Lanchester was criticised by Lord Rayleigh. However, Lanchester's intuition as to the importance of this law was correct. A more satisfactory approximate demonstration of this law of resistance

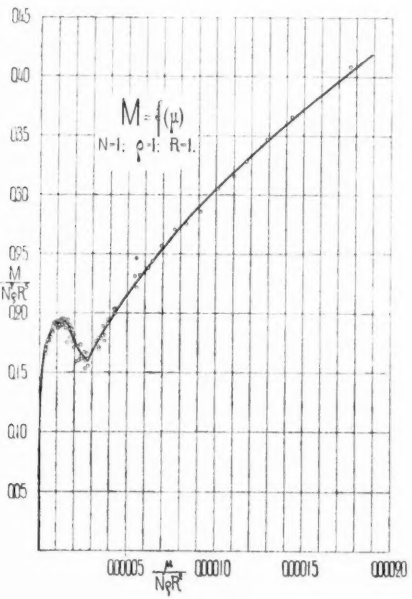


FIG. 115.

for plane surfaces moving lengthwise was given by Blasius in 1908, who expounded a theory published by Prandtl in 1904, but this result does not appear to have been confirmed experimentally. In my experiments on rotating discs, the law $V^{3/2}$ appears for the first time in a clear way and in connection with a well characterised change of régime.

The curves in Fig. 116 and 117 were obtained with the same experimental data as the curve in Fig. 115; only other dimensionless variables were chosen.

Referring to what has been said already, Fig. 116 represents the functional dependence between the frictional moment M and the density ρ, although experiments were carried on in water and in air under ordinary atmospheric conditions only. This curve shows that the couple always increases with the increase of density.

The curve in Fig. 117 represents the relation between the couple M and the reciprocal of viscosity $1/\mu$; it corresponds to the usual representation, when we take the velocity as the abscissa and the coefficient of resistance as the ordinate.

Fig. 118 shows the results of these experiments plotted logarithmically. This curve can be approximately replaced by four straight lines, the inclination of which determines the power n of each of the four laws of resistance:—

$$M/\rho N^2 R^5 = 0.912\ (\mu/\rho N R^2)^{0.134}$$
$$M/\rho N^2 R^5 = 0.191$$
$$M/\rho N^2 R^5 = 0.00407\ (\mu/\rho N R^2)^{-0.348}$$
$$M/\rho N^2 R^5 = 30.5\ (\mu/\rho N R^2)^{0.5}$$

where M = moment of frictional resistance on both sides of the disc;
R = radius of the disc;
N = number of revolutions per unit of time;
ρ = density of the fluid;
μ = viscosity of the fluid.

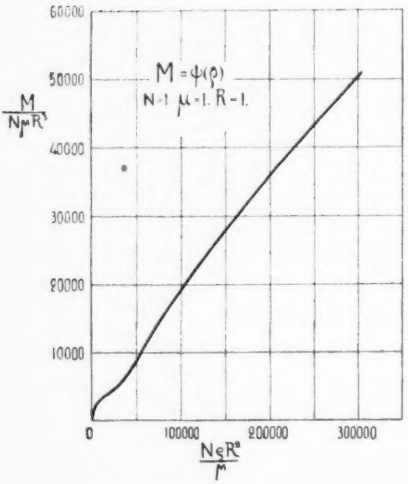


Fig. 116.

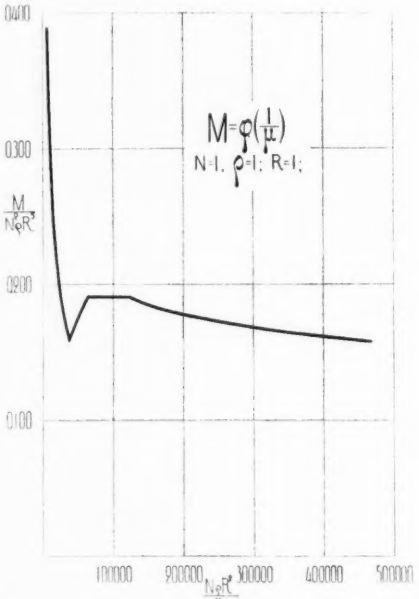


Fig. 117.

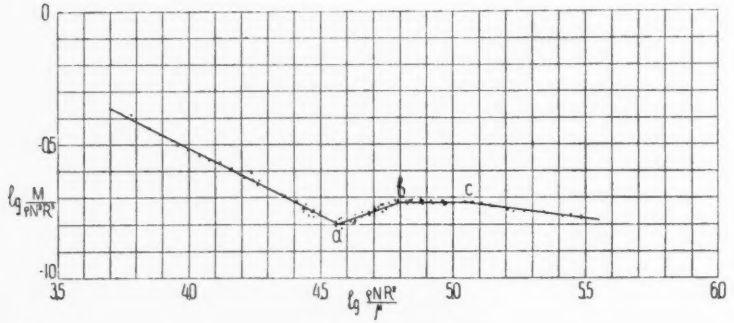


Fig. 118.

The last of these formulæ, which the author published in 1914, can also be written

$$M = 0.97\, R^4 \rho^{\frac{1}{2}} \mu^{\frac{1}{2}} \omega^{3/2}$$

where $\omega = 2\pi N$ is the angular speed of the disc.

The author also studied the frictional resistance of rotating discs with rough surfaces. He found that the shape of the curves is then considerably modified and that, applying the method of dimensionless variables, we no longer obtain a single curve. This circumstance shows the great influence of a new factor—the relative roughness (fifth " Bulletin of Koutchino," p. 30, 1914).

Fig. 119 represents an apparatus for the study of the distribution of velocity on the free surface of water when only one side of the disc touches it. It was found that in this case the couple is approximately half that when the disc is entirely immersed in water. The curves reproduced on Fig. 120 show that greater or lesser depth of immersion has but little influence upon the couple.

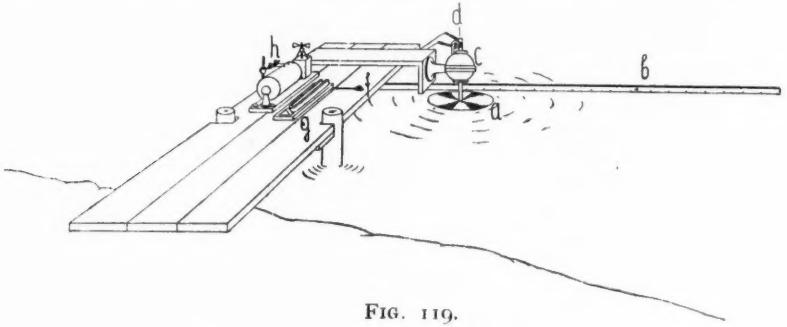


FIG. 119.

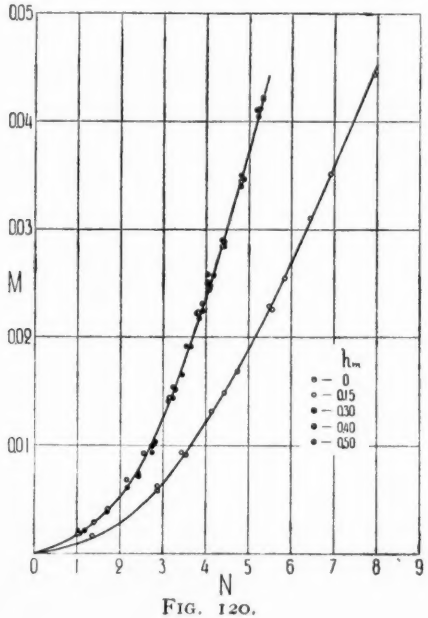


FIG. 120.

With the angular velocity used in the experiment shown on Fig. 119, the author observed that small particles of cotton placed on the surface of the water in the vicinity of the circumference of the rotating disc, describe straight lines. The empirical velocity law is

$$v = 0.915\ \omega r/(1 + 0.622\ l/r)$$

in which ω and r are the angular velocity and the radius of the disc, v the velocity of the water at a point P of the tangent line at a point M on the circumference of the disc, l the length of the tangent between P and M.

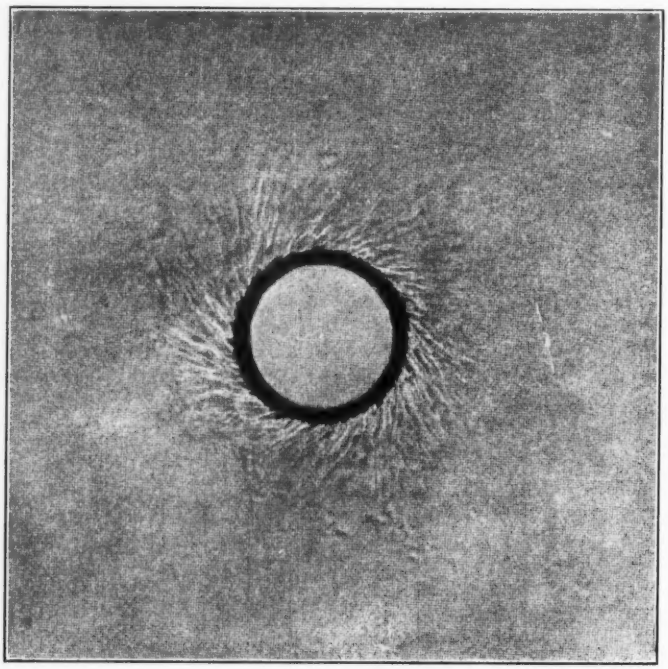


FIG. 121.

The critical speed when the motion ceases to be regular is characterised by the appearance of small air bubbles on the circumference of the disc and by a whistling sound. This occurred when $\log(\rho N R^2/\mu)$ reached the value of 4.94, which corresponds to the intermediate zone between points b and c on Fig. 118.

In the immediate vicinity of the circumference of the disc an annular swelling was formed and the fluid streaks seemed to have a rotational movement as if the motion was disintegrating into a system of vortex tubes adjoined to the disc.

Fig. 121 was obtained by revolving the disc in air above a plane surface covered with black paper and sprinkled with lycopodium powder as already explained.

Traces of adjoined eddies tangent to the edge of the disc appeared on the flow pattern. The annular space in the vicinity of the disc, where the lycopodium powder was swept away, corresponds to the annular swelling which is observed around the disc at the surface of the water.

(To be continued.)

ON A SIMPLE METHOD FOR SOLVING SIMULTANEOUS LINEAR EQUATIONS BY A SUCCESSIVE APPROXIMATION PROCESS

BY

J. MORRIS, B.A., A.F.R.Ae.S.

Simultaneous equations of three or more variables are notoriously troublesome to solve numerically and, moreover, are frequently sensitive for certain relative values of the variables. This usually precludes the use of the slide rule and in consequence resort has to be had to accurate working to an increasing number of decimal places involving much labour even with a calculating machine.

A method is here given which is applicable to certain classes of equations of frequent occurrence in mathematical physics and engineering science, which method is a combination of what is known as the Iteration process and the means of applying this principle to end moment distribution devised by Professor Hardy Cross.*

The method is best illustrated by an example. Suppose we wish to solve the equations

$$10x + y + 2z = 60 \quad . \quad . \quad . \quad . \quad . \quad (1)$$
$$x + 5y + z = 71 \quad . \quad . \quad . \quad . \quad . \quad (2)$$
$$5x + 2y + 100z = 2025 \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Equation

(1) $x_1 = 6$ obtained by putting $y = 0$, $z = 0$ in (1).
(2) $y_1 = 13$ obtained by using in (2) value of x_1 found in (1) and putting $z = 0$.
(3) $z_1 = 19.69$ obtained by using in (3) values of x_1, y_1 already found.
(1) $x_2 = 0.762$ obtained by using in (1) values of y_1, z_1 already found.
(2) $y_2 = 10$ app. obtained by using in (2) values of z_1, x_2 already found.
(3) $z_2 = 20$ app. obtained by using in (3) values of x_2, y_2 already found.
(1) $x_3 = 1$ obtained by using in (1) values of y_2, z_2 already found.
(2) $y_3 = 10$ obtained by using in (2) values of z_2, x_3 already found.
(3) $z_3 = 20$ obtained by using in (3) values of x_3, y_3 already found.
(1) $x_4 = 1$ obtained by using in (1) values of y_3, z_3 already found.

Thus the solution to the equations (1), (2) and (3) must be $x = 1$, $y = 10$, $z = 20$.

In practice it is not necessary to follow out the method in detail. It is much simpler to proceed in a tabular form as will be illustrated by the following equations :—

$$100x + 20y + z + 0w = 264 \quad . \quad . \quad . \quad . \quad (1)$$
$$0x + 100y + 10z + 3w = 355 \quad . \quad . \quad . \quad . \quad (2)$$
$$x + 5y + 100z + w = 422 \quad . \quad . \quad . \quad . \quad . \quad (3)$$
$$3x + 0y + 4z + 100w = 522 \quad . \quad . \quad . \quad . \quad (4)$$

* Analysis of Continuous Frames by Distributing Fixed End Moments. H. Cross, Amer. Soc. of C.E., May, 1930.

which are of the form

$$a_1x + b_1y + c_1z + d_1w = e_1 \quad . \quad . \quad . \quad . \quad (5)$$
$$a_2x + b_2y + c_2z + d_2w = e_2 \quad . \quad . \quad . \quad . \quad (6)$$
$$c_3x + b_3y + c_3z + d_3w = e_3 \quad . \quad . \quad . \quad . \quad (7)$$
$$a_4x + b_4y + c_4z + d_4w = e_4 \quad . \quad . \quad . \quad . \quad (8)$$

The tabular solution for the system of equations (1), (2), (3), (4), will be as follows:—

TABLE I.

	(1) $a_1x = 100\ x$	(2) $b_2y = 100\ y$	(3) $c_3z = 100\ z$	(4) $d_4w = 100\ w$
Ratios of distribution	$a_2/a_1 : a_3/a_1 : a_4/a_1$ 0 : .01 : .03	$b_1/b_2 : b_3/b_2 : b_4/b_2$ .2 : .05 : 0	$c_1/c_3 : c_2/c_3 : c_4/c_3$ .01 : .1 : .04	$d_1/d_4 : d_2/d_4 : d_3/d_4$ 0 : .03 : .01
Constants of equations	$e_1 = +264$	$e_2 = +355$	$e_3 = +422$	$e_4 = +522$
Distribution of -264	—	0	-2.64	-7.92
Distribution of -355	-71	$+355$	-17.75	0
Distribution of -401.61	-4.016	-40.161	$+401.61$	-16.064
Etc.	0	-14.941	-4.98	$+498.02$
—	-75.016	0	$+.75$	$+2.25$
—	$+11.020$	-55.102	$+2.755$	0
—	$+.015$	$+.148$	-1.475	$+.059$
—	0	$-.069$	$-.023$	$+2.309$
—	$+11.035$	0	$-.110$	$-.331$
—	$-.016$	$+.079$	$-.004$	0
—	$+.001$	$+.014$	$-.137$	$+.005$
—	0	$+.010$	$+.003$	$-.326$
—	$-.015$	0	$+.0001$	$+.0004$
Algebraic sum of quantities distributed	$+200.005$ $\therefore x = 2$	$+300.013$ $\therefore y = 3$	$+399.998$ $\therefore z = 4$	$+500.017$ $\therefore w = 5$

To explain this table. The object is to find as close approximations as may be desired to a_1x, b_2y, c_3z, d_4w respectively, where x, y, z, w are the values satisfying equations (1), (2), (3), (4).

Arrange the table in four columns, viz., one corresponding to each variable. At the head of each column write a_1x, b_2y, c_3z, d_4w. In the next row express the ratios $a_2/a_1 : a_3/a_1 : a_4/a_1$, etc., in the appropriate columns. Then in the next row put the values of e_1, e_2, e_3, e_4, with their correct signs, underlining the value of e_1. This will be the first value for a_1x. Next distribute $-e_1$ (in this particular example -264) in the proportions $a_2/a_1 : a_3/a_1 : a_4/a_1$, regard being had to signs, in the appropriate columns. Thus $a_2/a_1 = 0$, $a_3/a_1 = .01$, $a_4/a_1 = .03$. Hence the values to be distributed are 0, -2.64, -7.92. Next add the portion distributed to column (2) to the value above it in the same column and so obtaining $+355$ which sum is underlined. Next distribute -355 in the proportions $b_1/b_2 : b_3/b_2 : b_4/b_2$, viz., .2 : .05 : 0, in the appropriate columns. We thus

distribute -71, -17.75, 0, as in the table. Next, algebraically add all the quantities in column (3) and so obtain the sum $+401.61$, which is to be underlined. Distribute -401.61 as in previous distributions. Then likewise obtain the quantity $+498.02$, which is also underlined and then distributed in the appropriate manner. Next return to column (1) and sum the quantities *brought* over from the preceding three distributions, but do not include the sum underlined in the column. We thus obtain the algebraic sum -75.016, which we underline. This is next distributed in the same way as the 264 was, *i.e.*, we distribute $+75.01$ in the proportions 0 : .01 : .03. Continue the process in this way until the quantities to be distributed become small or negligible. Then add algebraically all the sums underlined for each column which, in the particular example, gives, after three circuits:—

$$100\,x = 200.005$$
$$100\,y = 300.013$$
$$100\,z = 399.998$$
$$100\,w = 500.017$$

So that the values required are evidently

$$x = 2,\ y = 3,\ z = 4,\ w = 5.$$

The method may be limited by the values of the coefficients in the equations being such as to make the process lengthy or divergent. This may occur if the major coefficients are not those of the successive variables in the successive equations as is the case in the example worked out.* Further, the method is evidently capable of extension and development.

* On further investigation it appears that the condition for convergency of the process for this example is that the following equation in λ (which is of general form), viz.,

$$\begin{vmatrix} a_1\lambda & b_1 & c_1 & d_1 \\ a_2\lambda & b_2\lambda & c_2 & d_2 \\ a_3\lambda & b_3\lambda & c_3\lambda & d_3 \\ a_1 & b_4 & c_4 & d_1 \end{vmatrix} = 0$$

must have its real roots numerically less than unity and, in the case of imaginary roots, the moduli must be less than unity. Similarly for the general case of n variables.

REVIEWS

The Romance of Flight

By Captain Norman Macmillan. Published by Evans Bros., Ltd. Price 2/-.

This book is written mainly for the younger generation and is intended to encourage their interest in the subject by telling them something about its history and something about modern aeroplanes and what it feels like to fly. Captain Macmillan has had considerable experience both in writing and piloting and it is not surprising to find that he has done his work very well.

It is possibly because of cost of production that such a considerable number of wood-cuts has been used for illustration, but it is unfortunate that accuracy of representation has been sacrificed in several cases. Good photographs are much superior to wood-cuts when accuracy is essential. Few errors have been noticed, but among them is a remark to the effect that Cody's 1912 aeroplane weighed half a ton. His military trials machine of that year, his best known machine, weighed over one ton complete. Again, a constant speed is not called momentum (see page 67), but the author gives a better definition in his own glossary, and the curve given without explanation on page 94 is not understandable.

The book should fulfil its object admirably.

Practical Solution of Torsional Vibration Problems

By W. Ker Wilson, M.Sc. Published by Chapman and Hall. Price 25/-.

This book is concerned with the torsional vibration of engine crankshafts and is written to assist the engine designer whose mathematical equipment may not be sufficient to enable him to use the theoretical treatises on this complicated subject. The mathematics the book contains, and there is necessarily a large amount, is of the type which should not trouble a competent designer.

The author, starting with the simple case of a fly wheel on the free end of a shaft fixed at the other end, proceeds to explain similar systems obtained by adding additional fly wheels, and having thus initiated his readers into the fundamentals goes on to deal with actual examples, increasing in complexity as he proceeds. There are also chapters dealing with stress considerations and various methods of damping and various types of torsiographs are also discussed. Though most of the examples are drawn from automobile, electrical and marine practice, the methods of calculation are applicable to aircraft engines and occasionally problems belonging to the latter are referred to in the text.

Subjects which can only be treated completely with the aid of complex mathematics generally present considerable difficulties to the designer, for the practical knowledge necessary to design is rarely combined with the special type of mentality possessed by a first class mathematician; and it frequently happens that complex solutions of engineering problems are useless for practical purposes owing to the time taken up by lengthy and difficult investigations. It is for this reason that a book such as this should be welcomed, as the methods of calculation it recommends are comparatively simple and appear to be adequate. In all cases where simplifying approximations are used the author is careful to

indicate the fact and to point out the conditions under which the approximation is likely to be near enough to the truth, and the errors involved.

Mr. Wilson has the gift of explaining difficult matters in a manner which makes them easy to understand, and his book should be of great use to those engaged in engine design.

How to Find Your Way in the Air

By C. W. Ferguson. Published by Sir Isaac Pitman and Sons, Ltd. Price 3/6.

This is a book on elementary navigation for amateur pilots, and those who read it carefully should have no great difficulty in finding their way about. Considerable space is necessarily devoted to matters concerning the compass, and the diagrams and descriptions are clear and easy to follow.

It is a useful little book and can be thoroughly recommended to those for whom it was written.

Some Problems of Modern Meteorology

Published by the Royal Meteorological Society. Price 3/6.

This book contains a series of papers by various authors, reprinted from the "Quarterly Journal of the Royal Meteorological Society," the aim being to give summaries of certain aspects of meteorology in the form of critical discussions of existing theories.

Of all scientific subjects it is probable that meteorology is the most difficult. In spite of the immense amount of investigation, both practical and theoretical, which has been carried out, there is not at present even a satisfactory theory of the circulation in the atmosphere, and the absence of such a theory makes it impossible to decide the relative importance of the various phenomena.

The publication of these papers is to be welcomed. It provides between the covers of one book a statement of the present knowledge on some of the more important aspects of the subject and this can only tend to the advancement of the science.

Stratosphere and Rocket Flight

By Chas. G. Philp. Published by Sir Isaac Pitman and Sons, Ltd. Price 3s. 6d.

This book mainly deals with rocket propulsion, and for the matter it contains the author has used very extensively articles which have appeared in "Science and Mechanics," "Wonder Stories," and also such papers as the *Daily Express*, *Sunday Referee*, etc.

It is not a serious contribution to the subject, as it is written in that style which is supposed by certain authors to appeal to the ordinary man who knows little or nothing of scientific matters and whose interest in the subject has to be aroused by "wonder" statements emphasised by exclamation marks.

There is nothing particularly novel about rockets. That they can rise to some height and that they can be made reasonably stable in flight can be confirmed by anyone who has ever seen a firework display. The height attained is already dependent on the amount of useful energy which can be packed into the rocket, and with this problem solved, interplanetary flight might be possible if a body can be given directional stability in a vacuum. How far we are from such a possibility is illustrated by a statement of the author, who states that

21,000,000ft./lbs. of energy is required to propel 1lb. beyond the attraction of the earth and that no known fuel possesses more than 5,500,000lbs. per pound.

The rocket will no doubt have uses. It was used for war purposes early in the last century and may be used for this purpose again. It may be used for investigation of meteorological matters at heights and there may be other uses, but the delivery of letters between continental capitals by rocket letter carriers let down by parachute on arrival at their destination seems hardly practical, if only on account of the extreme difficulty of ensuring that the letters would arrive at any particular place.

It would seem that the immediate problem before those interested in rockets is to pack more available energy into a given weight than has ever been previously accomplished, and, if they can do this they will have made a valuable contribution to general knowledge and may also be able to produce a rocket which will be really useful for atmospheric research.

Aircraft Progress and Development

By Capt. P. H. Sumner. Published by Crosby, Lockwood and Son, Ltd. Price 25/-.

This book is intended to be a history of the progress of aeronautical and engine design from the days of the hot air balloon to the de Havilland "Comet." As such, if it had been well written, it would have been a work of considerable interest, but it is clear on almost every page that the author does not understand the subject he is writing about. Errors of every description can be found everywhere, and of these the following is a sample: "When the aeroplane is flying at high speed the drag value due to high camber is much increased so that lift is then proportionally low." And there are many phrases which mean nothing whatever. The only thing that can be said in favour of the book is that it is extremely well illustrated.

The 583rd Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

A lecture, entitled 'Turbulence Near the Ground," was delivered to the members of the Royal Aeronautical Society on Thursday, 22nd November, 1934, at 6.30 p.m., in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, by Professor Wilhelm Schmidt.

In the chair: Lieutenant-Colonel J. T. C. Moore-Brabazon, M.P., F.R.Ae.S., President of the Society.

The CHAIRMAN: Professor Schmidt's name ranked with those of Professor Taylor, Professor Brunt, and others who had dealt with this complicated subject of aerodynamics. He was Professor of Meteorology in Vienna and for the last two years had been Director of the Central Meteorological Institute of Vienna, which was the chief meteorological service in Austria. Professor Schmidt was well known throughout the scientific world for his contributions to meteorological research.

TURBULENCE NEAR THE GROUND

BY

WILHELM SCHMIDT

Turbulent motion in open air must be studied in a way differing from that followed in laboratory experiments. We cannot choose or arrange for the most suitable conditions; we have to make the best of what nature offers; it is nearly impossible to stain air masses sufficiently so that they show streamlines—we have to judge their possible form from complicated effects. The results arrived at will depend upon the means at one's disposal and the way pursued.

Instruments

It is fundamental to start from accurate data of the wind velocity. To get its momentary value at a given point we used very light pressure plates. They consisted of wire rings of 20 cm. diameter, covered with fine muslin, attached to an axis at a distance of 50 cm. from the centre of the ring (see Fig. 1). If exposed to the wind they swayed, and the angle finally arrived at was a reliable measure of the wind velocity. We only used those that gave the same calibration. To have the movements fixed for later measurement they were taken by a cinema camera placed a little sideways. Marks on the plates and on the axles facilitated exact indications.

Our form of discs was of special advantage; they had a sufficiently small period of oscillation, so that they could reproduce rapid changes of air motion. The covering being permeable, the formation of rear eddies was suppressed and the final position was stable. As tests showed, it was not required to put the plates exactly normal to the wind direction; deviations up to 20° had no material effect.

It was easy to place several of those plates one above the other on thin arms protruding from a pole if one intended to get a vertical section. But in

most of our experiments we aimed at getting an entire cross-section, vertical as well as horizontal. Sometimes we used only two poles and attached a number of plates to horizontal wires stretched at different heights between them.

Still more suitable was a rigid construction of steel tubing, consisting of a frame of 6 m. height and 12 m. width, braced at the back. To facilitate the transport over turf, or especially over the frozen surface of lakes, it was placed on five sledge-runners. This made it easy to shift it to right angles to the wind, and one horse could easily move it to distant places (see Fig. 2).

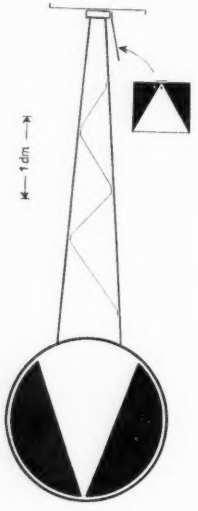


FIG. 1.

Pressure plate, front view. On top the axle sprung into a simple bearing, fitted with wire hooks for fastening. On the right side view of the plate, used for marking the exact axis in the photos. On the muslin stretched over the disc a similar mark. The brass wires supporting it are diagonally stiffened. Entire weight 11 *grams.*

Checking of Observations

Single rows of plates, as well as the frames with their 25 to 75 plates, were photographed in the same way with a frequency of two to seven exposures per second. For checking purposes the films or copies of them were vertically projected on a draughting-table. Here the apparent angles of every pressure plate were measured by a parallel-arm protractor, as used for geodetic work. By slide rules of special form the perspective contortions were taken into account, and the corresponding velocities directly arrived at. In spite of these facilities it was a rather troublesome work; an exposure of several minutes in open air sometimes exacted weeks of home work. No less than 300,000 single items of wind velocity were thoroughly worked out, about the same number are only recorded.

As it is impossible to take in at a glance all details of turbulent air motion, it is necessary to select only single aspects. To demonstrate it we used two methods. Firstly we plotted the momentary velocities of air at different points of a cross section, and put the figures in a rectangle corresponding to our frame

at the places of the different pressure plates. Then we drew lines of equal velocity (Isotachs) by interpolation. In Fig. 3 (picture 275), *e.g.*, the following is expressed: In second 55 near the right top there was a wind velocity of more than 8 m./sec. In the centre it dropped below 2.5 m./sec. Near the ground it was below 2.5 m./sec. a.s.o. By the corresponding procedure lines of equal wind pressure could be drawn.

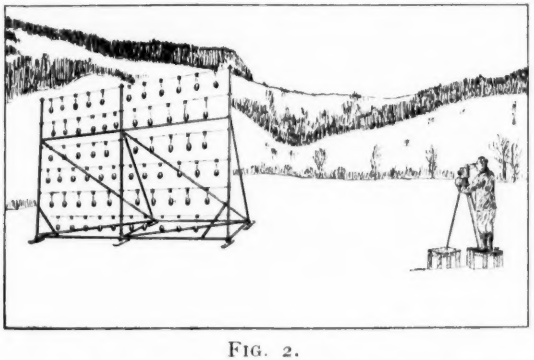


FIG. 2.

Movable frame with pressure plates on the frozen lake of Lunz: way of making pictures on a cinefilm.

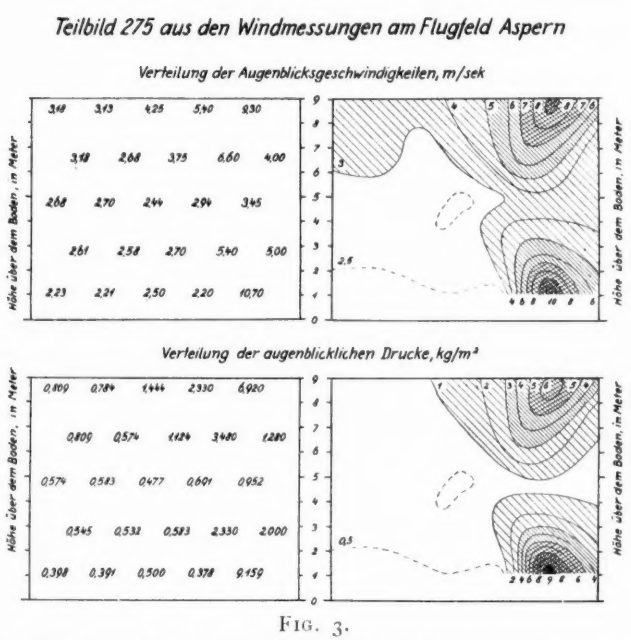


FIG. 3.

Construction of lines of equal velocity (top) and equal pressure (below) from observed values at different points of a cross section (left side). Data from the Aerodrome Aspern-Vienna.

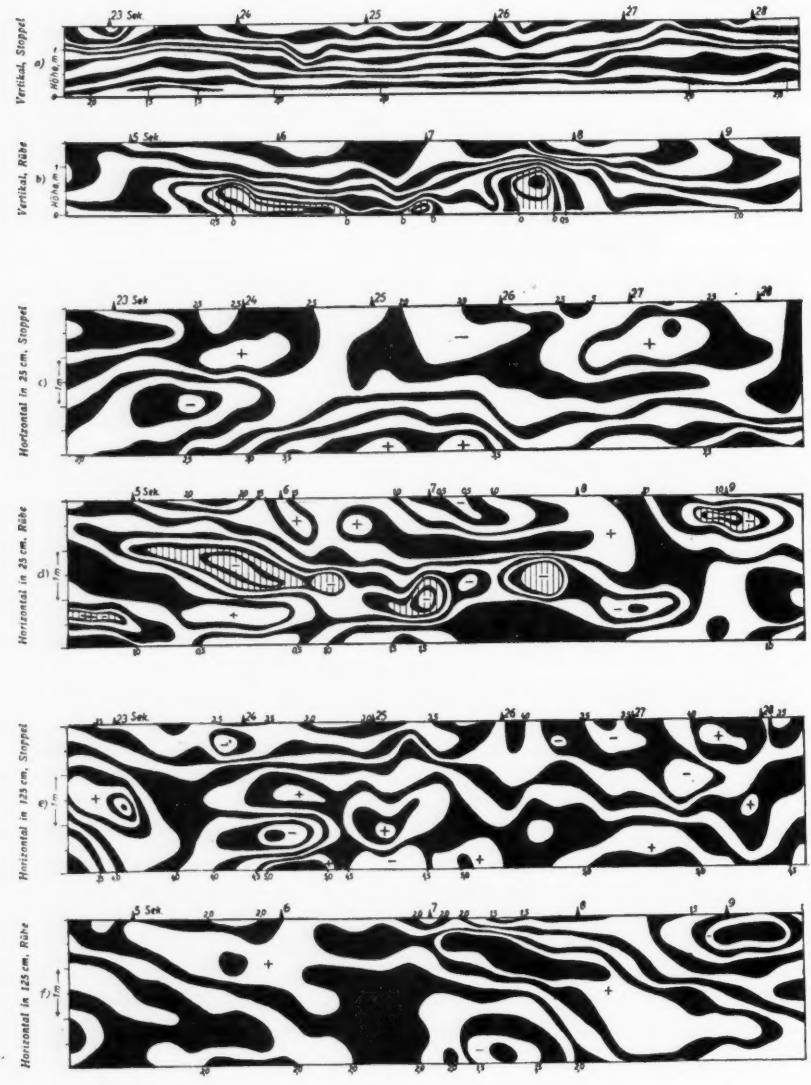


FIG. 4.

Wind records from Hommelsheim, October, 1928. Changes in velocity with time at different sections. Scale on the left metres, large figures on top time in seconds, small figures on top and below velocities in metres per second; dashed areas: negative velocities (motion against the wind).

(a) and (b) vertical sections, (c) and (d) horizontal at a height of 25 cm., (e) and (f) the same at 125 cm., (a), (c) and (e) taken over stubble field, (b), (d) and (f) over a field of turnips.

A second method is able to give the changes of velocity at certain points with time; the latter is plotted as abscissa, the height, *e.g.*, as ordinate. In the same way as above we may insert figures corresponding to the results of our measurements for every given moment and plate. The lines of equal velocity drawn between them are some sort of isopleths and not isotachs in the usual sense.

Velocity-changes with Time; Scarcity of Vortices

In Fig. 4 this method is applied: Lines of equal velocity are drawn for 25, 50, 75 . . . cm./sec. The spaces between subsequent lines are alternately blackened and left white. In the top strip (*a*), referring to a level stubble field, the lines on the whole run parallel to the ground—a characteristic of the normal increase of velocity with height. In the second strip taken over the corrected surface of a turnip field there are great irregularities; sometimes the movement was in reversed direction to the average wind; thus near the bottom from second 5.5 to 6.5, at a short moment about second 7, and in a very striking manner at second 7.8. It seems to correspond much more to our idea of a turbulent motion. It is generally thought that the fluid in such a motion is full of eddies and vortices. Let us see what shape the curves assume, if a real classic vortex is passing by. If its axis is horizontal we get a picture like Fig. 5. It is assumed

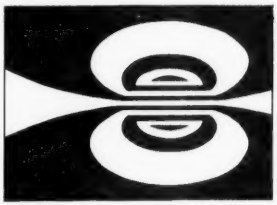


FIG. 5.

Form of lines for Fig. 4, when a classic vortex with horizontal axis is passing by.

that in the middle we have true vortex motion with a diameter of about one-third of the vertical extension of Fig. 5. Beyond this limit the circular velocity may decrease, so that there is no rotational movement.

If we examine our diagram Fig. 4 (*b*) we find a rather similar configuration, only at sec. 7.7. Only at this moment the motion may be explained by the assumption of a real vortex. In no other instance of this series (only a small part of it is shown in the figure) do we find a similar shape.

If one has ordinary pictures of streamlines, or others taken with a camera moved with a certain speed, one often gets the impression of many vortices forming the turbulent motion. Our method of representation gives a more trustworthy idea; every real vortex, no matter with what velocity it travels, must give a shape like Fig. 5. If we do not find this, there is certainly no vortex.

In the same way the scarcity of vortices is shown by all our other observations—be they taken over aerodromes (Aspern), over meadows (Vienna, Podersdorf), or directly on the shore of lakes (Neusiedlersee, Lunzer Untersa), or the sea (Wangeroog).

Another instance of the scarcity of real vortices in the general flow of free air is gained from the contemplation of growing cornfields from an elevated point. There one sees waves resembling those on water surfaces, but not identical with them, as there is no propagation of motion among the stalks. But we have never seen any detail that would lead to the assumption of a

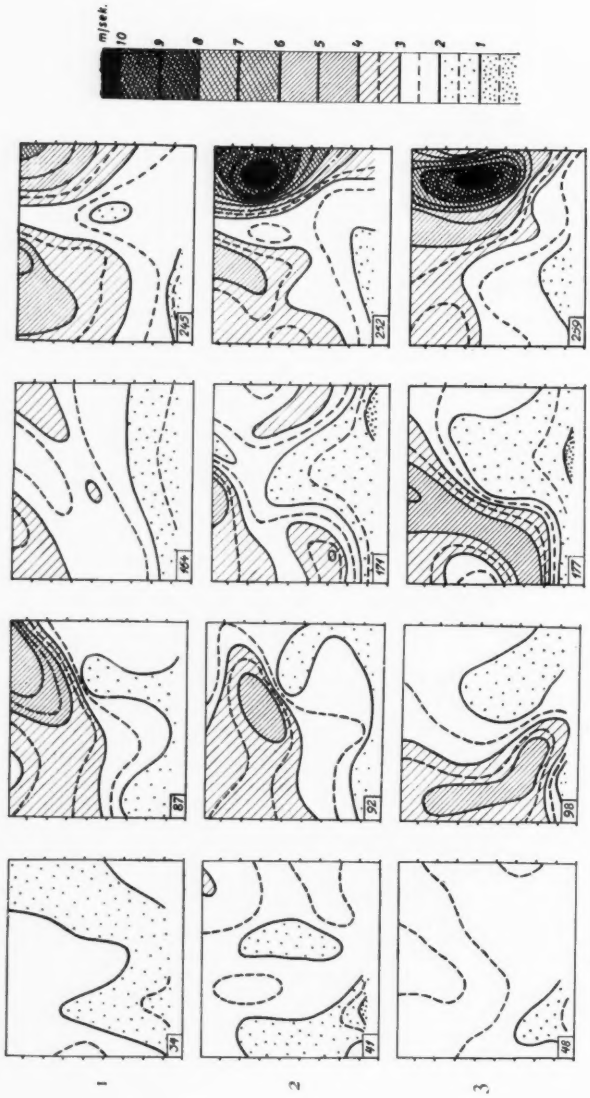


FIG. 6.

Velocity distributions over a front of 10 × 10 *metres from experiments at Aspern, July,* 1928. *Detail pictures of the whole series; the three exposures of each row taken at intervals of about* 1 *second. Scale of shading at the right.*

vortex. By the way, if vortices are essential for turbulent motion, they must occur also over the surface of water. I cannot imagine what visible effect they would have, and what surface forms might be attributed to them.

In Fig. 4 was given not only the distribution of velocity in vertical sections, but also in two horizontal sections laid at 25 and 125 cm. above ground. From (*c*) and (*d*) we get further confirmation of our deductions on the higher degree of turbulence caused by the turnip leaves. This holds good only for very moderate heights. Already a little above 1 m. elevation the wind over turnips shows less disturbance than over stubble-field. This might be due to a destruction of kinetic energy through the numerous little eddies over the rough surface of the turnip field.

This would be explained in the same way as the dissolving of compact water jets and the destruction of their energy by scattering them into irregular little eddies, as is usually done at outlets of barrages.

Velocity Distributions over Cross-sections

Other information may be got by our first method, the isotachs for single moments. In Fig. 6 examples of them are given. As the corresponding wind pressures increase with the square of velocity, the local contrasts in them are much greater. When there is a ratio of 4 : 1 in velocities at a distance of less than 2 metres (as at 8 metres height in the figure, picture 252), then the corresponding ratio of wind pressures amounts to 16 : 1 (*cf.* Fig. 2).

Most of our exposures were represented in this way. We may deduce from these the following general rules: There very seldom is a distribution of velocity approaching the theoretical increase with height. The most favourable case is that of air coming over a wide water surface as the Neusiedlersee, near Vienna. There we put up our posts on the gentle slope of its eastern bank. Winds from the west were a sort of " sea " wind, whereas those from the east travelled only over flat meadowland without marked obstacles. One easily sees the influence of the different surface character in Fig. 7. With sea wind, generally slighter horizontal differences and less change from one instant to the next; with land wind the highest contrasts are often found between left and right. We have already mentioned similar differences caused by roughness of the surface in the case of stubble and turnip fields.

From an inspection of subsequent pictures one gets the impression of jets intruding from higher layers like projectiles. These streams of high velocity often are rather stationary at the same place of the section. They frequently begin with a more horizontal expansion and gradually change to a more vertical position.

Correlation between Neighbouring Air-streams

To have positive values for linking of air motion at different places of a cross section we calculated the correlation coefficients for several pairs of pressure plates. Table I gives the values of an experiment made on the shore of the Neusiedlersee with the wind from the lake. We divided the whole sequence into two parts, according to a difference in mean wind velocity. Under Group I are given the coefficients for slighter velocity, at 4 metres height, 2.4 m./sec., under Group II those for higher wind, 3.8 m./sec. The left side gives the horizontal connection; it is more pronounced higher up, less near the ground, as might be expected. But it is surprising, that even at such small distances as our frame afforded, the values go down to 0.4 or less; above this space rapid changes have hardly any marked parallelism. Still more surprising is the fact that with high winds the correlation is much slighter.

The figures on the right side are inserted at the middle of the corresponding intervals; they indicate a somewhat smaller connection in the vertical direction,

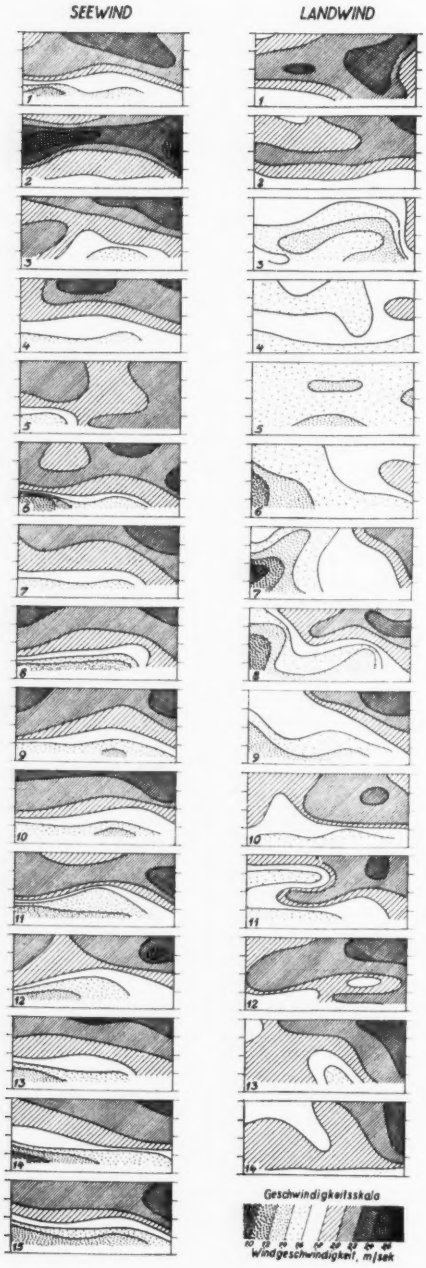


FIG. 7.

Velocity distribution over a front of 4×9 metres, taken on the shore of Neusiedlersee, October-November, 1927. Left, wind coming over 10 kilometres of free water surface; right, from over flat meadow land. Scale of shadings, given for velocity grades of 20 cm. p. sec. in right bottom corner.

also less pronounced at the bottom. The numbers for low and high winds differ in the same way as above.

TABLE I.

CORRELATION COEFFICIENTS, PODERSDORF, FEBRUARY 1ST, 1929.

GROUP I.

Height of plates, metres.	*Horizontal distance, metres.*				
	2	4	6	8	10
6	**0.88**	**0.80**	0.67	0.63	0.67
5	**0.83**	0.74	0.63	0.62	0.69
4	**0.82**	0.75	0.70	0.64	0.68
3	**0.82**	0.73	0.69	0.65	0.63
2	**0.80**	0.72	0.68	0.57	0.62
1	0.68	0.58	0.48		

Height of plates, metres.	*Vertical distance, metres.*				
	1	2	3	4	5
6					
	0.90				
5		**0.86**			
	0.89		**0.81**		
4		**0.84**		**0.77**	
	0.90		**0.78**		0.66
3		**0.83**		0.69	
	0.87		0.74		
2		0.75			
	0.83				
1					

GROUP II.

Height of plates, metres.	*Horizontal distance, metres.*				
	2	4	6	8	10
6	**0.66**	**0.55**	0.44	0.41	0.39
5	**0.61**	**0.53**	0.38	0.40	0.41
4	**0.57**	0.39	0.46	0.41	0.42
3	**0.65**	0.50	8.46	0.50	0.45
2	**0.59**	0.44	0.40	0.38	0.42
1	0.31	0.24	0.13		

Height of plates, metres.	*Vertical distance, metres.*				
	1	2	3	4	5
6					
	0.69				
5		**0.53**			
	0.71		0.48		
4		**0.54**		0.38	
	0.69		0.42		0.24
3		**0.52**		0.22	
	0.68		0.31		
2		0.42			
	0.55				
1					

Values over 0.5 in heavy; over 0.75 in very heavy type.

All this refers to wind coming over relatively flat ground. If there are obstacles, turbulence is markedly increased. Even as slight an obstacle as reeds is felt to distances of hundreds of metres. We found a most striking instance in our tests made on the frozen surface of the Neusiedlersee, Fig. 8. The free wind coming from the snow-covered ice showed nearly regular distribution of velocity. But when we put our frame 160 metres behind the small reed-covered island, hardly protruding above the surface, and no wider than 10 metres, there was a turbulence distinctly higher than in the wind coming from unobstructed space. At 9 metres behind the island the isotachs showed a very inconsistent motion.

Obviously rigid obstacles may cause somewhat greater disturbance than the bending reeds. This was tested by putting a board 1.5 metres high and reaching halfway across our frame in front of it. If the distance was only some metres the eddy on the lee side was very marked, especially behind the corner. At 20 and 40 metres the place and kind of influence was changed, but was still noticeable in striking irregularities. All this with an obstacle of very moderate height.

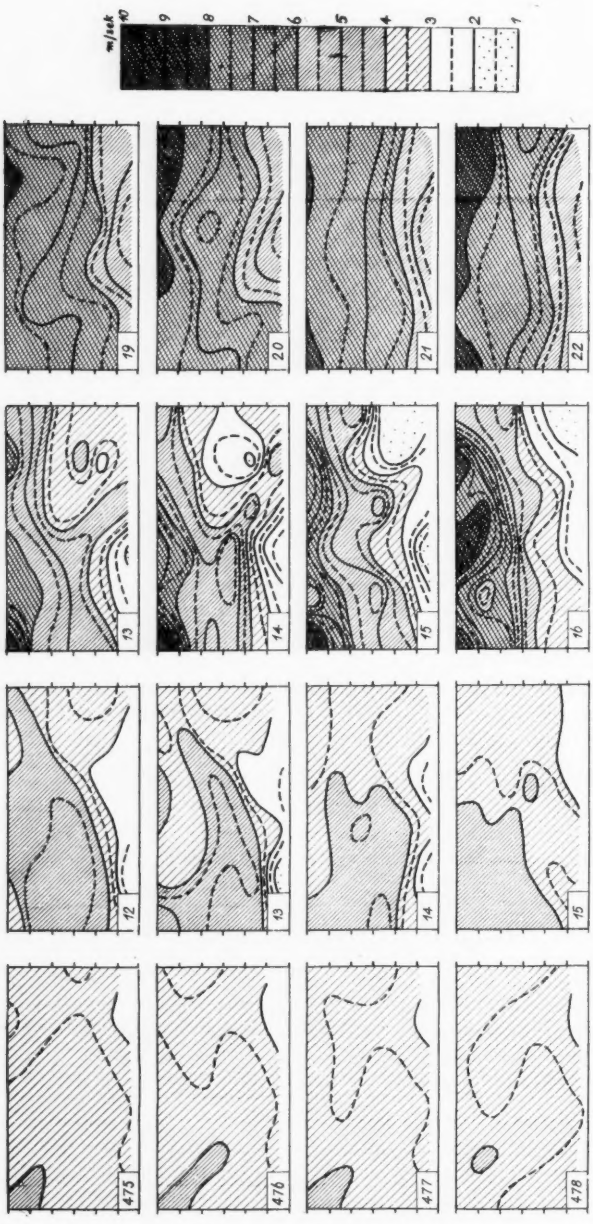


FIG. 8.

Velocity distribution over a front of 12 *metres width and* 6 *metres height in the neighbourhood of a small reed-covered island on the frozen Neusiedlersee. (a) and (b) taken in front of the island, i.e., without disturbance. (c) at* 160 *metres, (d) at* 9 *metres behind it.*

Regular Sequence of Gusts

In the case of rigid obstacles often eddies are generated in regular intervals. They detach themselves, travel with the average wind and cause a regularity in the sequence of gusts. This would not apply to the general motion of free air, although the superficial impression and also the inspection of records might lead to this assumption. We tested this by harmonic analysis of the results of our observations. But there certainly is no persistence of waves of exactly the same period and phase angle over the whole series of pictures. Therefore we divided it into parts each five times the tested wave in length. The results of harmonic analysis of all these parts were averaged. In this way the influence of change in phase angle or interference of neighbouring periods was eliminated. This was done for 18 different wave periods from 1 to 13 seconds. Longer periods were tested in a different way.

There was a lot of statistical work to be done. It was made possible only by the use of counting machines.* The result is given in Fig. 9. It shows the "gust spectra" for different heights deduced from three of our observations.

Gusts occurred at any interval, but with some of them the observed amplitude was highest. These particular intervals changed not only from one experiment to the other, but also with the same observation with different heights above ground. This latter statement seems essential for our deductions.* It is hard to imagine how regular sequences of gusts may be generated by surface friction, an assumption that might be favoured by laboratory experiments.

Such results can only be obtained by the use of apparatus without appreciable lag, such as our plates or hot wire instruments. Only for longer periods we used Dines' pressure tube anemometer fitted with a quick run.

Coefficients of Eddy-motion

A suitable expression of describing the form of motion is furnished by the "coefficient of turbulence or eddy-motion." We will not go into details so far as to give its value for single points and moments, but will stop at its application to different layers. If z is the height above the ground, v the average wind velocity, then the down flux of momentum going through or the frictional force acting on horizontal unit surface is given by

$$F = -A\,(dv/dz),$$

where A may be called the coefficient of vertical exchange by turbulence (Austauschkoeffizient). For the same moment and the same place the same A governs the flux of any other quantity that is connected with the air mass.

Now H. Ertel† has given a formula for calculating this coefficient from records taken at short time intervals:—

$$A = \rho\,(\partial_v M dv/dt)/(dv/dz)^2$$

where ∂_v denotes the standard deviation of velocity and $M\,(dv/dt)$ the mean value of change of velocity with time, ρ the density of the air.

It is obvious that we cannot get directly dv/dt but must replace it by the changes during finite intervals—the value of A may be increased by it, but as in our case we have a very frequent sequence of readings, this increase must be very limited.

Table II gives the values arrived at in this way; they cover a wide range, from 0.04 to 5,800 absolute units. They increase with height, in some cases clearly approaching a formula

$$A = A_1 z^{(n-1)/n}\ (A_1 \text{ the value of } A \text{ at } z=1),$$

* I must express my thanks to Prof. L. W. Pollak (Prag) for his advice and assistance; a great part of our material was worked out by the Czech Statistical Institute.

† *cf.* Gerlands Beitrage zur Geophysik, **25**, H 3/4 (1930).

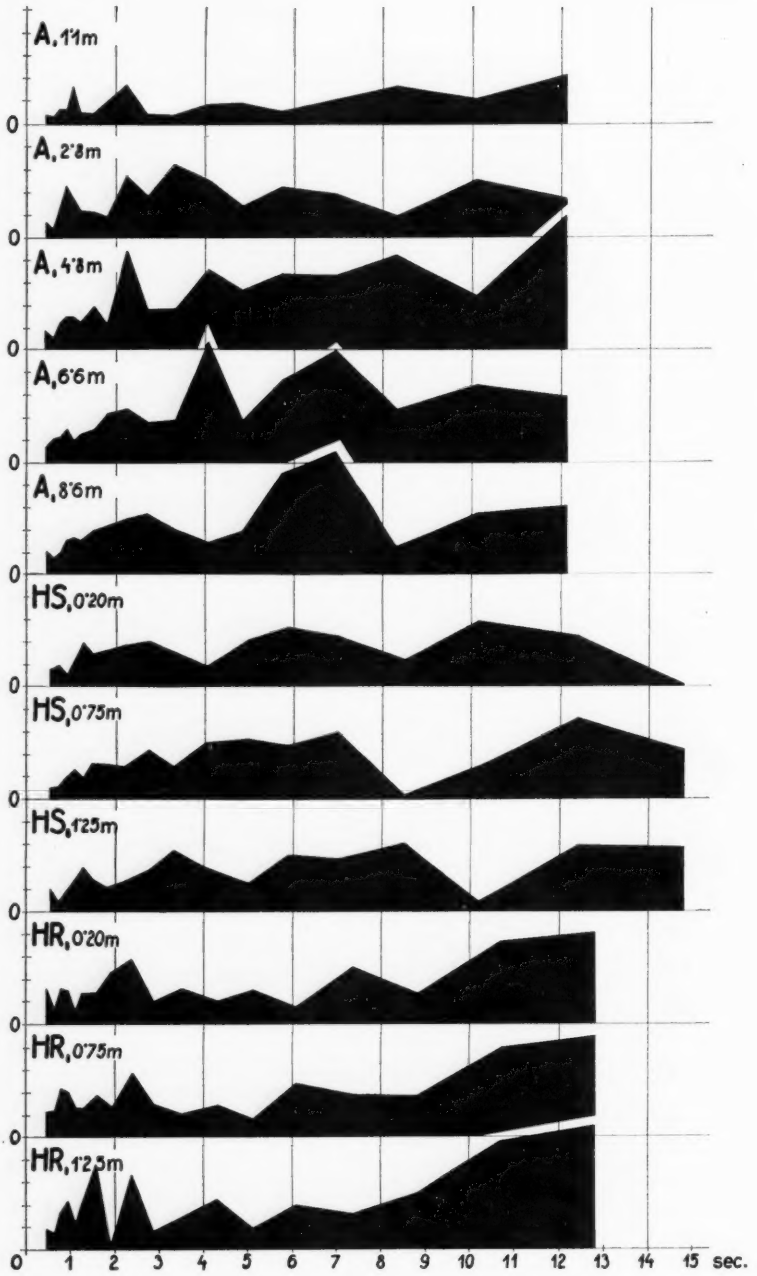


FIG. 9.

"Gust spectra," amplitudes of wind oscillations of different periods. A=observations taken at Aspern (aerodrome, flat grass land), HS=Hommelsheim (over stubble field), HR=Hommelsheim (over turnip field). The figures near these indications give the height above ground.

corresponding to an increase of wind velocity with height according to $v = v_1 z^{1/n}$. For n different values are found; over flat grass land 4.6 to 5.3, over stubble field 4.2, over turnips 2.4. From these figures one may easily deduce the vertical gradient of A in each case.

TABLE II.

VALUES OF THE COEFFICIENT OF TURBULENCE, A, CM.$^{-1}$ G. SEC.$^{-1}$.

Place.	Height of plates, metres.								
	0.8	1.8	2.8	3.8	4.8	5.8	6.8	7.8	8.6
Aspern 1 ...		1.2	7.2		26		53		90
,, 2 ...		1.8	12		35		67		72
,, 3 ...		1.7	12		37		73		93
Podersdorf ...	0.8	1.05	1.15	2.0	1.7	3.2			
Wangeroog 1...	0.8	32	261	840	890	1210	2360	5820	
,, 2...	2.9	16	38	45	79	95	143	524	

Place.	Height of plates, metres.		
	0.20	0.75	1.25
Hommelsheim. stubbles ...	0.04	0.48	6.6
,, turnips ...	0.19	0.31	0.29

Aspern 1. 2, 3 subsequent parts of the same observation.

Podersdorf : wind coming across the lake.

Wangeroog 1 and 2 taken the same day, before noon and in the morning, on the beach, with 500 and 12m. width respectively, of dry sand in front.

Hommelsheim : both series taken at the same day.

Records of motion afford one means for finding the values of our coefficient. Similar methods and calculations may be based on different interchanges as on the flow of heat (detailed temperature records are required) or on the flow of water vapour a.s.o. As there is close connection between all these, the progress made in one is applicable to the others, *e.g.*, it was possible to measure in a new way the actual evaporation from open grass land.

A is a very sensitive indicator for the state of turbulent motion. If we start, *e.g.*, from our experiments behind a board we find a smooth curve with height in free motion. But behind the obstacle one had the highest values of A, amounting to more than ten times the common one, at a height of nearly 1 m., at 1 and 4 metres horizontal distance in the rear. At 20 m. the greatest disturbance was found about 2 m., at 40 m. distance nearly 3 m. high. This shows clearly how the strongest eddy motion rises and also affects higher layers gradually.

There is certainly a distinct influence of friction on the surface, but at the same time probably also of meteorological conditions, chiefly stability of air strata and heat exchanges on the ground. This leads to the following discrimination.

Forms of Turbulence

Turbulence may be generated in two ways: Firstly by *dynamic* action. This is the form mainly studied in laboratory work. In open air, interaction with the second way always takes place; the ground is heated by incoming radiation, the conditions grow less stable, warmer air rises upward and causes the cooler air from above to come down. This sort of turbulence may be called *thermic*. On the other hand, outgoing radiation also has its influence. The cooling of the lowest layers leads to very stable conditions and diminishes or sometimes suppresses the dynamic turbulence. We may notice here the difference in gustiness during day and night hours.

It is impossible to separate both effects. Even in the laboratory a study of the influence of static conditions is very difficult—in open air we have to reckon with all degrees of interference of both. Therefore a multitude of experiments under various conditions is a necessary foundation for analysis.

Some insight into the essence of pure thermic action may be gained by an experiment. One puts air under stable conditions into a trough closed on all sides. The trough is then turned upside-down. As observed through glass walls, the heavier masses do not descend as a whole, but in small drops that gradually diminish in number but grow in size. The same, only in reverse sense, must happen if the lowest layer is overheated. In nature the heated masses at the bottom form at first small but numerous upward streams, as above they diminish in number and their size increases. We see the uppermost tops of such streams in the cumulus clouds in summer-time.

Extension to Greater Heights

So far I have treated motion of the lowest layers of the atmosphere. The results allow immediate application for landing conditions of aeroplanes or for construction of all sorts. But we may learn from them something about higher layers. What we have observed on a smaller scale may be transferred to greater heights by the law of similarity connected with the name of Reynolds. Whether we may apply it exactly is not certain, as in the laboratory we may assume in open air a sort of boundary layer of different character. Moreover, only high velocities near the ground correspond to the usual velocities found higher up. But we may, if not quantitatively, at least qualitatively transfer our results. That at least is certain—that real vortices also in the free atmosphere are not essential for turbulent motion. If there is a more passive layer, gusts will be produced in this by air streams, intruding like projectiles from faster travelling layers. Following our assumption deduced from experiments over different fields, one would think it possible that roughness of surface may smooth down the turbulence at a given height. Over a large uniform forest the turbulence obviously is increased in the lower layers; but from a certain distance upward it may be damped. This fact may be found distinctly only at greater distances from the border of the wood, as this produces disturbances of its own. In these and other ways our experiments may lead to ideas that may be tested by arrangements of other forms, used in kites or aeroplanes, or observed by practical aviators.

As our researches involved extensive observational and statistical work, I had to rely on the help of several collaborators. I herewith express my thanks to them, and particularly to the *Notgemeinschaft der Deutschen Wissenschaft* in Berlin, which entrusted the necessary funds and lent us the greater part of the required outfit.

Discussion

Professor G. I. Taylor (Fellow): One or two things which Dr. Schmidt had not mentioned would be interesting to know, particularly from the instrumental point of view. The plates apparently had a period of oscillation of about 1 second since they were 50 cms. long. Would they swing across if they were released in still air or would the damping make the swing aperiodic? Presumably that question was considered in analysing the results. It was certainly very curious to see back flows against the wind, as disclosed in some of the pictures, and in this connection the inertia characteristics of the plates required consideration when the results were being interpreted. The correlations between the velocity of the wind at different horizontal and different vertical distances seemed extremely instructive and valuable. The pictures shown by Dr. Schmidt would suggest that the distance in which the correlation fell from, say, 1 to 0.7 increased almost uniformly with height. That also seemed an instructive idea.

Dr. G. C. Simpson (Meteorological Office): Turbulence was of great importance to the aviator, but he did not propose to deal with that side of the question that evening. He preferred to deal with its meteorological aspect. Turbulence was another word for "mixing," and practically all meteorological phenomena depended on the mixing of the air. The original ideas of atmospheric mixing were associated with vortices set up in the air as it passed over obstacles. Such unco-ordinated motion was difficult to express in mathematical form, but about 20 years ago Professor G. I. Taylor in this country and Professor Schmidt in Austria devised a method for applying mathematics to mixing of this nature. They pictured small parcels of air being picked up and transported a stated distance and then mixing with the air again. It was then found that the actual observations could be largely represented mathematically if the average distance through which the air was transported between two mixings was a stated amount. This average distance is expressed in the so-called coefficient of turbulence.

Although there had been, ever since the mathematical problem had been solved by Taylor and Schmidt, a great deal of work done on turbulence in the atmosphere, the first really large scale observations were undertaken at Cardington in connection with airships. Professor Schmidt in the experiments he had described this evening had been mainly concerned with small scale turbulence; the work at Cardington was mainly concerned with the larger scale turbulence associated with gusts and lulls and squalls. Turbulence occurred in the atmosphere on many different scales; there was the small turbulence such as that described by Professor Schmidt, then the larger scale as studied at Cardington; from these one can go on to squalls, depressions and even the general circulation of the atmosphere, all of which were turbulence in its different forms. It appeared as though one could arrange the different kinds of turbulence in a continuous scale, one passing imperceptibly into the other, but this probably was not correct as different physical factors were responsible for turbulence of different kinds. The turbulence due to an obstacle exposed to a current of wind was obviously different from the large scale turbulence of the general circulation of the atmosphere due entirely to thermal conditions.

Professor Schmidt, in the latter part of his paper, had pictured currents of warm air ascending, causing mixing and finally large cumulus clouds. He thought that in England they had gone one step further than Professor Schmidt in this problem. The work which was described before this Society by Sir Gilbert Walker last year had a bearing on the motion and mixing of air due to thermal instability. The formation of cells and long streamers of cloud indicated much more orderliness in the mixing than had usually been supposed.

Professor D. Brunt: Some work had been done in this country that was, he thought, strictly comparable with that of Dr. Schmidt, namely, by Mr. Scrase, who had observed the changes of wind at very short intervals of time by cinematography. Mr. Scrase found that a very large number of eddies had periods of only a fraction of a second. It could be deduced from his results that about a quarter of the eddying energy in the atmosphere on one occasion was associated with eddies of periods of at most one-fifth of a second. Professor Brunt was not very clear whether Professor Schmidt's method took account of eddies of such short periods.

At the end of his paper the lecturer had given an expression for the *Austausch* coefficient $A(z)$, involving a parameter n. It had been shown by Mr. Sutton in this country, and by several Indian workers, that the parameter n was subject to a very big diurnal variation. Its value at night was very different from its value in the afternoon. That gave rise to a certain amount of uneasiness when he was reading the paper. Could Professor Schmidt assure them that the diagrams, for example in Fig. 2, were taken at comparable times of day? Were the observations over the stubble field taken at a time of day

when one could reasonably expect to get comparable results? The time at which the observations were taken was not, so far as he could see, indicated in any part of the paper and he should like a little information on the subject.

Professor Schmidt had shown a slide giving a comparison of results obtained from different wind velocities. He wondered whether those observations were taken on occasions when the lapse rate was comparable. The parameter n, which entered into the *Austausch* coefficient, depended on the lapse rate of temperature, and therefore if a comparison were made of light and strong winds, presumably it was necessary to take account of the possibility that the lapse rate was widely different on two occasions. These points were not put forward in any sense as criticism. He would like to express his admiration for the patience that Dr. Schmidt had displayed in facing the reduction of 350,000 observations.

Mr. H. E. Wimperis (Fellow, Vice-President): The experimenter having come to the conclusion that very little vortex motion was to be seen in the experiments, how had he been able to satisfy himself that a simple pendulous instrument of rather long period, and of unstated damping, would be able to give a result that could be interpreted when subject to fluctuations in air flow at very varied periodicities, and doubtless very varied intensities? From experience in other fields Mr. Wimperis would have felt rather frightened of an instrument of that kind, but he must accept the results obtained by Dr. Schmidt with his greater experience in the meteorological field.

The lecturer had referred to the interest which aeronautical engineers would naturally take in the question of turbulence. One of the problems of to-day was: Why is the " lift " on landing, or taking-off, either from grass or over the sea, much more than one would expect it to be. That was an unsolved problem. He would not suggest that what they had heard that night was a solution of that difficulty, but the more they could learn of what the air was doing in the neighbourhood of the ground the nearer they would be to the solution. Their interest in turbulence at higher altitudes was limited, chiefly, to the strength of aircraft. But there was an interest about which in the future years a good deal more ought to be heard. Those who studied the flight of birds could account for practically everything that happened in gliding and soaring, but there was a section of opinion which indicated that there was a certain form of soaring flight in which energy was entirely taken from the difference in the velocity of the wind. That might account for the way in which some birds behaved. Whether men would be able to behave in that same fortunate fashion remained to be seen. He mentioned it as a problem similar to that which the lecturer had brought forward, though carried to greater heights.

Mr. H. Sutton (Fellow): How was the instrument calibrated? He had found the utmost difficulty in calibrating wind instruments for very low wind speeds. He wondered whether the instrument was reliable in low winds with a heavily stratified atmosphere, such as obtained during the nocturnal inversions. It was known, for example, that the drag of a sphere was profoundly influenced by the degree of turbulence present. Did the same calibration hold for the pressure plate instrument for the cases in which the air was very turbulent and when turbulence tended to be damped out by the inversion?

Dr. Schmidt gave the power law of velocity and height and the quantity n there, as Professor Brunt had mentioned, was one of the fundamental quantities in the study of turbulence. In a wind tunnel the value of n was about seven, and varied relatively slowly with the degree of turbulence. Mr. Sutton inquired whether Dr. Schmidt had verified the fact that power laws were valid in the case of inversions. In some work that the member had done he had had to make the assumption that power laws of velocity held even in large inversions and large lapses, but he had no exact information on this point. He imagined that it was conceivable that in large inversions one did not get power laws at

all. In such cases it would seem the atmosphere was stratified vertically by separate air streams. Had Professor Schmidt any idea from his work of the variation of n with the vertical gradient of temperature?

Lieutenant-Colonel E. GOLD (Meteorological Office): More than 25 years ago he was working in the Institute at Vienna with Professor Schmidt. At that time they had some doubt as to whether the instruments used for recording the temperature of the upper air gave results which could be trusted from the point of view of lag. They decided to make an experiment to test it, and he was struck at the time by the great ingenuity which Professor Schmidt had displayed in devising the simplest possible methods of arriving at the best results. When Colonel Gold saw the kind of anemometer the Professor used it excited his admiration. The nearest approach to it which we used in this country consisted of a metal plate swinging about on its own axis. It was nothing like as sensitive, and was subject to the eddying effect which Professor Schmidt had avoided by his method. Reading the paper, one of the things which struck Colonel Gold was the effect on the wind which the lecturer had found, of a small island of reeds, probably less than a metre high, at a distance of 160 metres. One of the difficulties of meteorologists was to decide upon a suitable position for an anemometer. He (Colonel Gold) was now completely depressed, for he was convinced that there was no suitable position for an anemometer in the British Isles. Another thing which struck him was Professor Schmidt's conclusion that the larger turbulence above the turnip field was replaced by a smaller turbulence at a slightly greater height. The Professor suggested—and Colonel Gold supposed it was correct—that that conclusion could be applied to the turbulence above a forest. One of the most surprising things to meteorologists years ago was the discovery that above a wood the atmosphere was intensely more turbulent than it was in any ordinary situation or even above buildings—they put an anemometer above a forest rather expecting to find that the trees combed out the wind and gave more or less steady flow, but actually they found a very great degree of turbulence. To-night he had learnt that that very great degree of turbulence immediately above a wood might be replaced at a greater height by even less turbulence than if the wood were not there. That was a piece of information of very great interest to him and no doubt to aviators too.

Dr. N. A. V. PIERCY (Fellow): The vertical jets observed occur on days when the temperature lapse rate is more or less normal.

In regard to application to the aeroplane, Dr. Piercy thought there were two effects to consider. First, the velocity changes illustrated in the film were of so slow a nature that he imagined them of significance in connection with the control of the aeroplane nearing the ground, and not with its performance. On the other hand, the coefficients of eddy viscosity appeared high, unless he was wrong as to how they had been calculated, and should affect appreciably the aerodynamical force on the aeroplane. He hoped Dr. Schmidt would correct these views if he disagreed.

An immediate application of the last aspect was as follows: Various small wind tunnels were now projected in this country. If for some reason the open jet type were not desired, a 4ft. (say) enclosed tunnel could be made for some £500, but the building to house it would cost more than double this amount if streamline flow was to be obtained. In view of Dr. Schmidt's observations, how far was streamline flow desirable? Some years ago the wind tunnel at East London College was, he understood, claimed to give somewhat different results than those of some other tunnels installed in higher buildings. The case was of particular interest because the comparative lowness of the laboratory appeared to give the stream an appreciable eddy viscosity, whilst, on the other hand, designers had frequently said that the tunnel provided a good guide to full-scale

work. Professor B. M. Jones' well-known paper on the streamline aeroplane had done much to clear up the matter, but two papers read since, first by Mr. Relf and now by Dr. Schmidt, to some extent re-opened the question, particularly in regard to maximum lift. Work was proceeding on the effect of screens, but it should be profitable to associate with this the question of laboratory dimensions.

Mr. A. FAGE (Fellow): They knew from experiments which had been made in America that the turbulence in the air at appreciable distances from the ground did not influence the critical flow past a sphere, and so it was not expected to influence the flow in the boundary layer of an aeroplane wing. Had Dr. Schmidt found in his experiments close to the ground any evidence of small-scale turbulence, in other words, turbulence of the type associated with the flow in the boundary layer of a wing of an aeroplane? The question was raised because there was evidence that the maximum lift of some wings was sensitive to small-scale turbulence, and if such turbulence were present it might have a direct bearing on flight near the ground.

Mr. L. F. C. SIMMONS (Associate Fellow): Reference had been made to one or two experiments at the laboratory with hot wires for the purpose of measuring the vast changes which occurred. Those measurements were made at the top of a tower about 60ft. high. One experiment was to measure the speed and direction of the flow and to ascertain the changes that took place. They were very surprised to find that on one occasion there were up currents ranging from +50ft. per second to −50ft. per second in about 0.8 of a second, those variations being associated with the passage of a very intense horizontal vortex. It was the only one they found in a series of records. The rare occurrence of this type of disturbance was in conformity with the results obtained by Dr. Schmidt. With reference to Fig. 6 in the paper, that seemed to show that the amplitude of the longer period disturbances increased with height. But were those changes serious? Dr. Schmidt had not given the velocity scale, but Mr. Simmons thought that on the screen those changes were of the order of 40 cms. per second.

Dr. SCHMIDT agreed.

Mr. SIMMONS: Such changes were relatively small in comparison with those registered in the National Physical Laboratory experiments, which in one case varied from 55 to 125ft. per second in the course of about 0.8 of a second. On another occasion they observed a change in the vertical velocity amounting to 25ft. per second in the course of about 1/30th of a second. It seemed to Mr. Simmons that if the gust spectra were extended to include the short period changes, some very large ordinates would be added to the curves.

F. W. LANCHESTER, LL.D. (Hon. Fellow) (*communicated*): There was, he thought, good reason to suppose that atmospheric turbulence was always associated with vortical motion, for in practice, that was to say, in real fluids, vortices were always accompanied with rotational cores, excepting in the special case of a surface of kinetic discontinuity, and that condition was only transitory. Wherever such a surface was set up viscosity resulted first in establishing a stratum of rotation in place of the definite discontinuity and this breaks up into cores which become the centres of cyclic or vortex motion. In any fluid disturbance the whole movement could be accounted for in terms of rotational and irrotational motion, which was equal to saying that turbulence consists essentially of an agglomeration of vortices or superposed vortical systems.

Dr. Schmidt was perfectly right in his remarks as to the importance of thermal effects, and on that point it might be remarked that motions generated by differences of temperature and density commonly contained rotation; it was in fact the only method by which rotation could be communicated to a perfect

fluid and consequently it was one of the important methods in the case of the real fluid.

Where he could not follow Dr. Schmidt was in his reference to Fig. 5. It appeared self-evident to him that the observed result of a single vortex ring would depend upon its presentation and he could see no reason to suppose that it should always take the form suggested in Fig. 5. And furthermore, where there was a mass of vortices superposed—a jumble of vortices—he could not imagine that it was possible to recognise their existence by comparison with any simple diagram.

There was no doubt that where a single obstacle, such as a wall or building, was concerned there was definitely a system of vortices thrown off, whose cores were something of the form of croquet hoops; whatever the shape of the building or wall might have been those tended to assume a more or less regular form and gradually grew in size as dissipated in the lee of the obstacle. An instructive example of vortices generated in this way might be observed in water when rowing a boat or paddling a canoe. The paddle derived its reaction by the generation of vortex motion in the water and each time the paddle was dipped and withdrawn a vortex half-ring was generated. There was direct evidence of this in the two dimples in the surface of the water denoting the vortex terminations (the ends of the half-ring on the surface of the water). By careful observation also it was possible to see the rotary movement in opposite directions in the regions of these dimples. Similarly, if a paddle were held stationary in a running stream, a succession of such vortex half-rings might be seen.

The problem of a wind obstructed by a wall was similar, and in such a simple case there was no question that the major disturbance was the generation of vortex motion initiated as a surface of kinetic discontinuity which immediately generated rotation and broke into discrete vortices. It could not be too clearly insisted that a surface of discontinuity in itself constituted vortex motion and might be expressed as such, but it could not develop into discrete vortices until the surface of discontinuity had become a stratum of rotation, because even a single vortex without a core, in which there was rotation, was impossible—it involved an infinite quantity of energy.

It was to be observed that when discrete vortices were generated, as when a smoke ring or vortex ring has formed, they gradually increased in size and became more " sluggish." What happened was that streamlines flowing round the vortex body entered the vortical system from behind, as described and plotted in a paper read by him (Mr. Lanchester) some twenty years ago.*

In view of the complications which had to arise when a jumble of vortices and rotational cores were superposed, as in a turbulent mass of free air, it appeared to him impossible by the mere examination of diagrams such as those presented in Figs. 6 and 7, to say whether there were vortices or vortex motion or not.

He congratulated Dr. Schmidt on the use of pressure planes of muslin or permeable material. In physical experiment the view was that the act of investigation must have interfered with the phenomenon or " course of events " observed, and that all physical measurements were initially suspect on this account. The measurement of air velocity by a pressure plane would have seemed to be a particularly flagrant case, and the experimenter would have quickly realised the truth of the modern view (above) by the irregularities consequent on the vortices generated in the region of the " dead water." Dr. Schmidt recognised this difficulty and used a form of pressure plane calculated to disturb the conditions of flow as little as possible.

* Proc. Inst. Automobile Engineers, Vol. IX., p. 213, Fig. 23.

Reply to Discussion

Professor Schmidt, in reply to Professor Taylor, said that for calibration the plates were drawn through perfectly calm air along a wire stretched horizontally. It was easy to ascertain the angle at which the plates stood for a certain speed of relative movement. Tests were also carried out in moving air, using a fan and comparing with a calibrated Robinson anemometer. As the weight of the plates was small—11 grammes for the lighter type—the mass impact of air was of the same order of magnitude as the mass of the instruments, therefore the coefficient of damping was very high, nearly aperiodic, as given by both procedures. As a rule he was sure the indications on the plates were correct to about three cms. per second in steady wind; if there were changes of wind, deviations of 10 or 15 cms. per second might occur in few cases, but they could not in any way alter the results.

The irregular movement in the case of the turnip field was certainly not due to the backward swing of the plates; such would be impossible, because the duration of the oscillation would be of quite another order of magnitude. He would give another instance. Curves were not derived from a single plate, but based on cross sections with readings on 25 points. There were always several plates which gave the same strange result, movement against the wind. One had to take this for granted.

In regard to what Dr. Simpson had said, Professor Schmidt would lay stress upon a special meteorological application of quantitative notion of turbulence. They were now able to calculate by independent methods the coefficient of vertical exchange (equal to the coefficient of turbulence in vertical direction). If the results were the same they might derive the amount of the vertical flux of heat or water vapour, etc., by taking the vertical lapse rate of temperature or vapour pressure and multiplying it by that coefficient. So in one case he had got the amount of evaporation from meadow land mentioned in the paper.

As to the observations of Mr. Scrase, to which Mr. Brunt had referred, Professor Schmidt was glad to mention that in the Austrian experiments they used intervals of less than 0.2 seconds. This was certainly sufficient, as Dr. Scrase stated, that "an interval of one-fifth second is sufficiently short to include most of the small fluctuations and that for purposes of comparison there is little advantage in taking readings more frequently."

It is true, that turbulence and its lapse rate—the latter given by the parameter n—vary greatly with heat exchange from soil. To fix all relations even his number of nearly 1,000,000 different observations was not sufficient. But as to the pictures for Figs. 4*a* and 4*b*, they were taken immediately one after the other with only ten minutes' interval between. So the heating of the ground was obviously quite the same in both cases, the differences found being due entirely to different roughness of the ground.

If the power law does not hold, the motions in different layers could not be steady. Accelerations that then must occur would give a still suitable indication of such a state.

The last slide was intended only to show what differences might be found in the open air. There was a common value for A of about 50 or 100 absolute units, but if the flow came from smoother ground to rougher ground the turbulence was very much increased. This was the case at Wangeroog to which he had directed attention, where there were values of 500 to 800. It would be possible but not easy to look out for a connection between A and n from the observations made. If one desired to apply the connection between the coefficient of turbulence and the flux of heat, or water vapour, etc., one must make the observations to get at the coefficients of turbulence at the same time as the other experiments were

made. So one could get rid of the disturbing influence of change in the parameter n. That would also apply to the turbulence above sea and land, which Mr. Wimperis had mentioned. The lecturer thought that near the coast the largest differences were to be found. Farther out at sea they were not so marked. If birds over level land or open sea make use of eddy motion for their soaring flight, it seems that in mountainous regions—as for instance in Austria—they soar only in places where there is a constant upward motion of air. Then turbulence is not necessary.

He thought that Mr. Sutton's question had been partially answered. The influence of turbulence present in air was greatly avoided by using a permeable coating of the pressure plates; so rear eddies could not form.

With reference to Colonel Gold's remarks, Porfessor Schmidt feared that nearly all anemometers were not in a sufficiently good position to admit of strict comparison. He was himself content if he obtained one good position so that he might compare the results at different heights. It was very hard, even under favourable conditions, to compare two places some distance apart.

Dr. Piercy mentioned the wind tunnel. One may suggest that in making true model experiments the state of turbulence in the tunnel should be gradually changed, to get its influence. Even in judging wind force according to Beaufort's scale—it is in some way an energy scale—one is influenced by the amount of eddy motion present. In one instance one put down 2 Beaufort, whereas, according to the indications of an anemometer, the velocity corresponded to a value of at least 4 Beaufort. The air motion in this case was very steady, the temperature distribution being that of a strong inversion.

Mr. Fage had asked a question about the boundary layer. Professor Schmidt was not quite sure how far the boundary layer extended near the surface of the field. But there is surely a certain layer of different behaviour of motion, as *e.g.*, indicated by the change of prevailing periods with height, see Fig. 9.

He had seen the place where Dr. Simmons carried out his experiments: it was on one side of a large field, but with constructions at the back. It was possible that under these conditions one would sometimes get real vortices, as was the case in the one instance referred to. In giving the particulars about the gusts (see Fig. 9) the amplitude was rather low, because Dr. Schmidt took only the mean of the whole experiment. Dr. Simmons' high figures would have come down also to, say, 30 or 40 cms. per second if he had averaged the whole of his observations as the lecturer did.

In conclusion, Dr. Schmidt thanked them for the reception they had given his paper.

The CHAIRMAN: Their thanks were due to Mr. Wimperis for bringing them down with rather a sudden, though desirable bump, to the consideration of the relationship between Dr. Schmidt's lecture and aeronautics. Mr. Wimperis had mentioned the very interesting fact that increased lift occurred when the aeroplane was very near the ground. Neither Dr. Schmidt's nor any lecture on meteorology was out of place in their Society. Science advanced on such broad fronts that one never quite knew who was really ahead or who was lagging behind. Some branches could not be checked. Eddington and others could determine the exact temperature of the centres of stars, and one could not check it. On the other hand, if someone predicted that it would be a fine afternoon and it rained, that someone was told all about it. That was very unfair. They had a lot to learn in meteorology. It was a little odd that one could predict to the exact second the time of an eclipse, whereas one could not tell the ordinary man in the street whether or not he should take an umbrella. That was an example of the difficulties which had to be encountered on the broad front of scientific opinion.

They owed a great debt of gratitude to Professor Schmidt for what was really a *tour de force*. He came there and instead of reading a paper, which was a comparatively simple thing to do, he threw it away metaphorically and spoke to them on a subject of absorbing interest in a foreign tongue. Very few of them could speak on that subject in their own tongue. When they remembered that Dr. Schmidt had come from Vienna, risking the possible turbulence of the sea and the lack of turbulence of our London air, their gratitude went out to him for his physical keenness, and also for the mental dexterity which he had displayed.

THIRTY YEARS OF THEORETICAL AND EXPERIMENTAL RESEARCH IN FLUID MECHANICS

BY

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(*Continued from page* 348.)

12. *Skin Friction and Momentum*

In section 8 the author's apparatus for the study of skin friction, based on direct application of the momentum theorem, has been described (Fig. 99). In a paper published in 1914, this idea was further developed and it was shown that it is possible to calculate approximately in this way the skin friction and the distribution of air velocities in different régime.

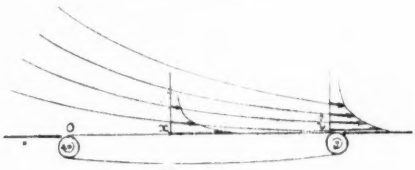


FIG. 122.

Let us consider, for instance, the case of the apparatus which we have just mentioned. The frictional force F acting on the belt (Fig. 122) between $x=0$ and an arbitrary value x will be

$$F = -\mu \int_0^x (du/dy)_{y=0}\, dx.$$

Applying the momentum theorem, we can write also:—

$$F = -\mu \int_0^x (du/dy)_{y=0}\, dx = [\rho \int_0^\infty u^2 dy + \int_0^\infty (p-\rho_\infty)\, dy]_x \quad . \quad . \quad (1)$$

In the more general case when the velocity at infinity is not O but U, this equation becomes obviously

$$F = -\mu \int_0^x (du/dy)_{y=0}\, dx = [\rho \int_0^\infty u\,(u-U)\, dy + \int_0^\infty (p-\rho_\infty)\, dy]_x \quad . \quad (2)$$

Let us apply the simplifying hypothesis that above the belt the streamlines are approximately parallel straight lines, and therefore

$$(du/dy)_{y=\text{const}} = \text{const.}$$

Hence in this case $p=\rho_\infty=$const. and equation (1) becomes

$$[-\mu x_1 (du/dy)=\rho\int_y^\infty u^2 dy]$$

According to the hypothesis made, this equation is exact for any value of y and by differentiating it we find

$$\mu x (d^2u/dy^2)=\rho u^2.$$

By integrating this equation and noting that at an infinite distance from the belt, u and du/dy simultaneously tend towards zero, we can write

$$du/dy=-(2\rho/3l\mu)^{\frac{1}{2}} U^{3/2}.$$

Hence the frictional resistance experienced by a belt of breadth b is

$$F=b\,(\tfrac{8}{9}\rho\mu lU^3)^{\frac{1}{2}}=0.814\,b\,(\rho\mu lU^3)^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad (3)$$

and the distribution of velocities above the belt

$$u=U/[1+(\tfrac{1}{6}\rho U/\mu l)^{\frac{1}{2}} y]^2.$$

These results were published in 1914 (fifth "Bulletin of Koutchino," p. 26-29).

In 1921 v. Kàrmàn, considering the case of a fluid moving along a flat plate, admits that $p=p_\infty=$const. and that outside a boundary layer of thickness $\delta=f(x)$ the velocity defect $(U-u)=0$.

With this hypothesis equation (2) becomes

$$-\mu\int_0^x (du/dy)_{y=0}\,dx=\rho\int_0^\delta u\,(u-U)\,dy.$$

By differentiating this equation with respect to x we have

$$-\mu\,(du/dy)_{y=0}=\rho\,(d/dx)\int_0^\delta u\,(u-U)\,dy. \quad . \quad . \quad . \quad (4)$$

v. Kàrmàn further supposes that the law of velocities is:—

$$u=U\,(2\delta-y)\,y/\delta^2.$$

Introducing this value in equation (4) he finds by integration the function $\delta=f(x)$ and afterwards the total friction

$$F=(4/\sqrt{30})\,b\,(\rho\mu lU^3)^{\frac{1}{2}}=0.73\,b\,(\rho\mu lU^3)^{\frac{1}{2}}.$$

A slight modification of my initial method leads to an analogous result.

Instead of admitting that $(du/dy)_{y=0}$ has a constant value along the plate, we may suppose that the mean value of (du/dy), between the leading edge $x=0$ and any point x on the plate, is proportional to the value $(du/dy)_{y=0}$ at x:—

$$(1/x)\int_0^x (du/dy)_{y=0}\,dx=a\,(du/dy)_x \quad . \quad . \quad . \quad . \quad (5)$$

where a is, in first approximation, a constant, not only when $y=0$, but also for sufficiently small values of y. By substituting this value in equation (2), one has approximately, by reasoning as above,

$$F=-\mu\int_0^x (du/dy)_y\,dx=-\mu a x\,(du/dy)_y=\rho\int_y^\infty u\,(u-U)\,dy$$

and

$$\mu a x\,(d^2u/dy^2)=\rho u\,(u-U).$$

By integrating with respect to y, and taking into account that $(u-U)$ and du/dy simultaneously tend to become very small at a small distance $\delta=f(x)$ where function f is still unknown, we find

$$(du/dy)_{y=0}=(\rho/3x\mu a)^{\frac{1}{2}} U^{3/2}.$$

Introducing this value in equation (5), we have

$$a = 2.$$

Finally

$$F = (\tfrac{8}{3})^{\frac{1}{2}}\, b\, (l\mu\rho U^3)^{\frac{1}{2}} = 0.816\, b\, (\rho\mu l U^2)^{\frac{1}{2}} \quad . \quad . \quad . \quad (6)$$

With this same approximation in the case of an endless belt instead of equation (3), obtained with a rougher approximation, one obtains the equation

$$F = (2/\sqrt{3})\, b\, (l\mu\rho U^3)^{\frac{1}{2}} = 1.157\, b\, (\rho\mu l U^3)^{\frac{1}{2}} \quad . \quad . \quad . \quad (7)$$

When comparing equations (6) and (7) we see that the resistance is $\sqrt{2}$ greater in the case of an endless belt in contact with the air on a length l between two fixed planes, than the resistance of a flat plate of same length moving lengthwise.

The author has also extended this theory (fifth " Bulletin de Koutchino," p. 40-41, 1917) to the case of turbulent motions by replacing the coefficient of viscosity μ by the generalised coefficient ϵ of Boussinesq admitting that this coefficient has the form

$$\epsilon = a\rho l\, |u| \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

where a is a dimensionless constant, ρ the density of the fluid, $|u|$ the absolute value of the difference between the actual mean velocity and the velocity which would be observed at same point if the frictional resistance on the boundaries were zero; l has the dimension of a line.

In a recent paper (1929) Prandtl took the Boussinesq coefficient under the form

$$\epsilon = a\rho l^2\, |\partial u/\partial y|.$$

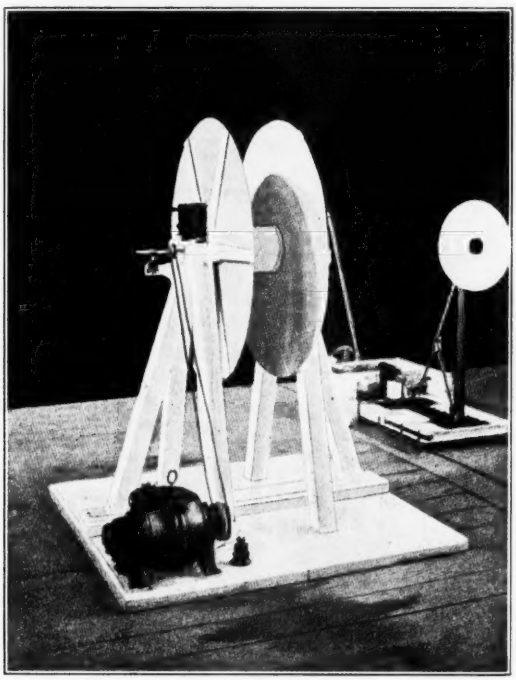


FIG. 123.

The author obtained formula (8) by examining the problem of velocity distribution in points sufficiently distant from the surface of a rotating rigid cylinder (forced eddy—tourbillon forcé). The author found that if the friction torque experienced by a rotating cylinder of radius c is proportional to the square of its angular speed, the velocity power law must be of the form

$$V^2r^3 = \text{const.} \quad . \quad . \quad . \quad . \quad . \quad (9)$$

provided the ratio r/c is sufficiently great, V is the velocity and r the distance of the considered point from the axis of the cylinder. Formula (9) shows that circulation around the cylinder tends to zero when r increases indefinitely. This result appears to be confirmed by the experiences on the lifting force of cylinders rotating in a stream (Magnus effect). The results obtained by Lafay, Ackeret (see Fig. 81) and Elliot G. Reid seem indeed to show that the lifting coefficient and consequently the ratio K/Vc of circulation K to speed V decreases, or at least does not increase, when the ratio $\omega c/V$ increases, *i.e.*, if for a given angular velocity ω of the cylinder, the air velocity V diminishes. This point is of importance and it would be worth while to elucidate it accurately by experiment.

The author's apparatus for the study of velocity distribution around a rotating cylinder is shown on Fig. 123. This cylinder rotated between two motionless discs.

Fig. 124 shows the arrangement used to measure the speed distribution over the belt of the apparatus represented on Fig. 99. Fig. 125 and Fig. 126 show the arrangement used to measure the frictional resistance by the momentum of the air swept off by the belt.

Experimental data obtained with these apparata are given in the fifth "Bulletin of Koutchino."

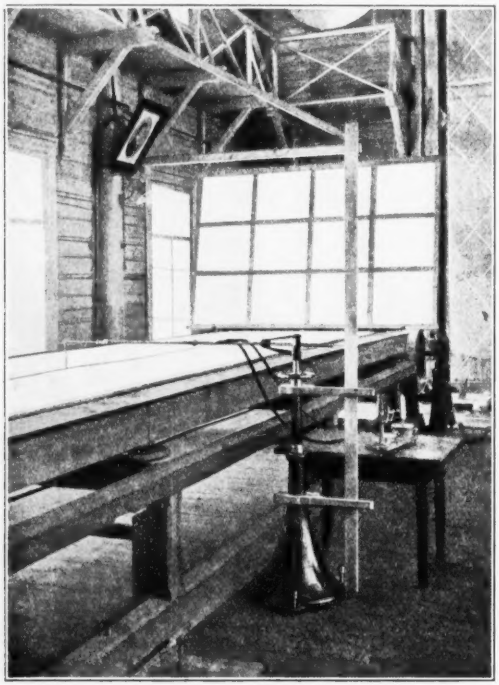


FIG. 124.

13. *Periodical Fluid Motions*

In this section we will consider two examples in which interchange of "régime," and consequently of eddy configuration, is going on periodically. In the earth's atmosphere and on the sun cyclones are produced by the effect of unequal distribution of temperature and density and the rotation of the globe. On the sun, the sun-spots which may be considered as eddy formations, appear periodically. We may ask ourselves if such motion could not be discussed from the standpoint of the dynamics of viscous fluids? Let us consider the apparatus shown on Fig. 127.

A glass globe (diameter $D = 40$ cm.) filled with water, with a small quantity of air left above the water, can turn steadily round a vertical axis. A small eight-vaned rotor 4 cm. in diameter, placed in the middle of the sphere is set in

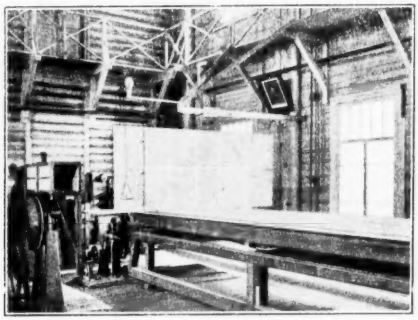


FIG. 125.

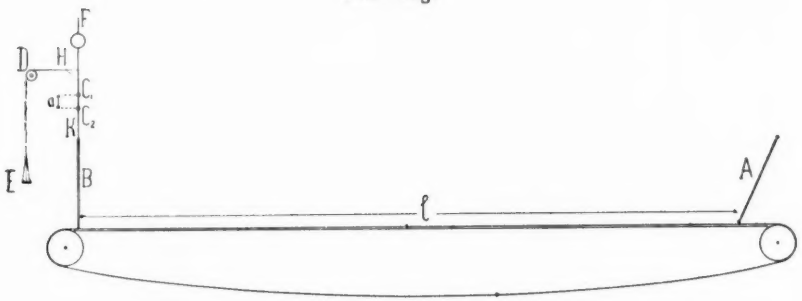


FIG. 126.

motion by a small electric motor rotating with the globe. The angular velocity of the rotor inside is greater than that of the globe and has the same direction.

In the construction of this apparatus the author reasoned as follows:— When the small rotor is set in motion, the glass globe remaining motionless, the fluid motion obtained must resemble somewhat the circulation of the atmosphere, caused by the difference of temperature at the equator and poles (Fig. 128*a*).

The rotation of the sphere around its vertical axis, in combination with the circulation maintained by the rotor, will deviate the streamlines and stimulate the formation of one or several eddies similar to those shown in Fig. 128*b*.

We can often foresee and explain the character of the motion of a viscous fluid, being guided by the analogy of gyroscope. It is sufficient to replace in the mind the circulation of which one foresees the appearance (an effect of unequal distribution of temperature, of viscosity, etc.) by a small gyroscope and to realise

the position the latter will tend to adopt under the influence of the composition of rotations.

The second phase cannot last long owing to the external and internal friction, and the first and second phase will succeed one another periodically.

Experiment has confirmed this reasoning in its general aspect. Fig. 129 gives a photographical reproduction of the two phases such as they can be observed.

Usually one single eddy is formed, but sometimes another eddy appears opposite to the first. When the number of revolutions per second of the sphere and rotor were respectively 0.89 and 24.5, the mean period, including both phases, was 1 minute 36 seconds.

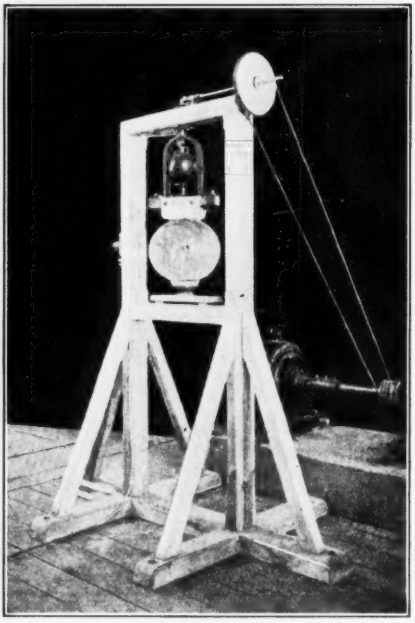


FIG. 127.

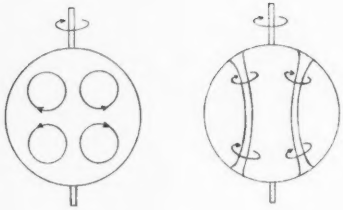


FIG. 128.

Apparata analogous to those described, but larger in size and modified in such way as to take into consideration all the influencing factors, could be usefully employed in aerological and solar research institutes.

Another kind of periodical interchange of eddy configuration was found by the author in the following way:—He filled with water the glass container of Weiher's apparatus for the study of water-spots, leaving above the water but a small quantity of air. Setting the small rotor of the apparatus in uniform rotation, he observed the succession of three phases of which Fig. 130 gives a photographic reproduction.

First Phase.—Along the axis of the cylinder we see the formation of an air column, a multitude of air bubbles around the rotor and above the latter an air cone. After a certain time, during which the air tube swells gradually, the diameter of its upper section reaches that of the rotor, and the phenomenon enters into its second phase.

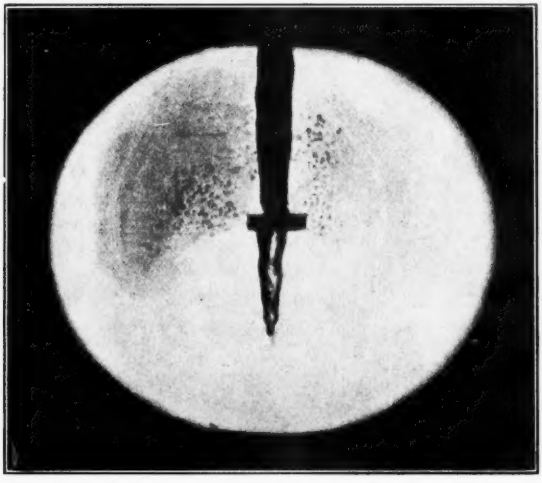


FIG. 129.

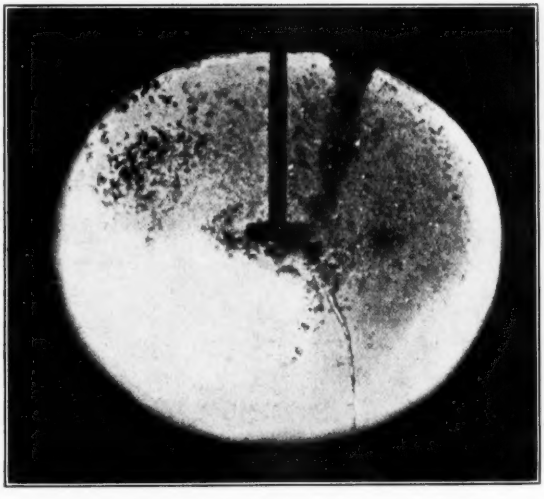


FIG. 129*a*.

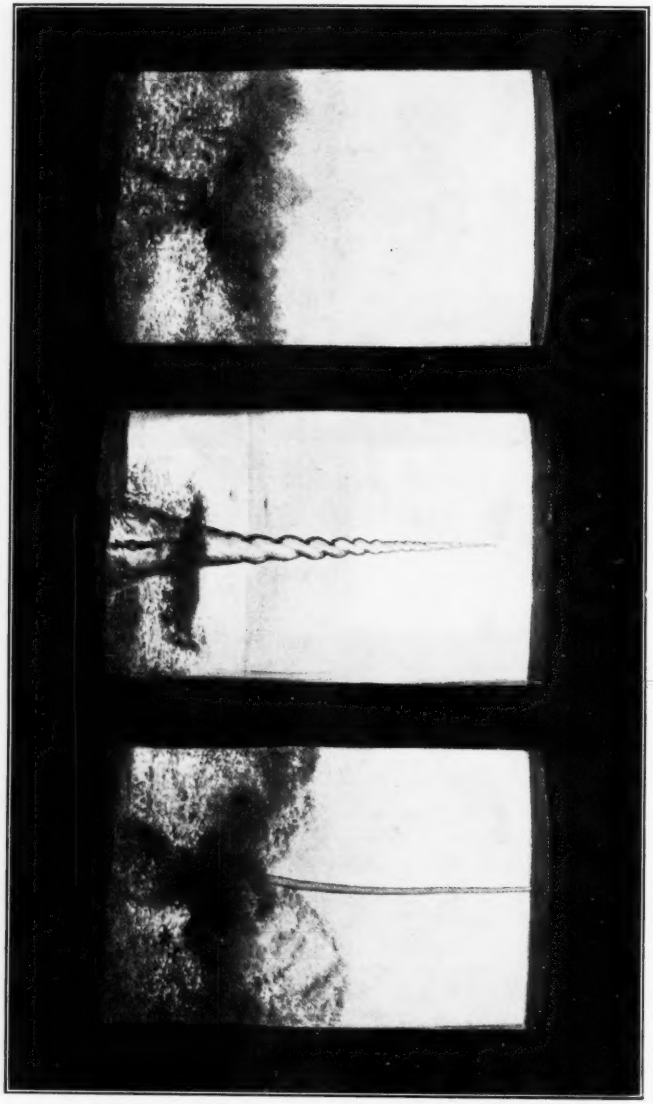


FIG. 130.

Second Phase.—The air tube takes the shape of a helicoidal cone, rises from the bottom of the container and slowly shortens. This second phase is accompanied by a characteristic humming sound. The cloud of air bubbles surrounding the rotor decreases visibly in volume.

Third Phase.—When the lower end of the helicoidal cone of the second phase reaches the rotor, the air is dispersed with sparkling in all directions. Almost at the same instant, the air tube descends to the bottom of the container and phase one starts anew.

The dimensions of the apparatus were:—Diameter of the glass receptacle 30 cm., its height 58 cm., diameter of the rotor 4 cm. When the number of revolutions of the rotor was 61 per second, the duration of the first phase was 13.1 second, of the second phase 10.7 second and of the third a fraction of a second.

The period of interchange of régime in the second apparatus depends upon the size and shape of this apparatus, the diameter and angular velocity of the rotor, the density and viscosity of the fluid and acceleration due to gravity.

14. Pendulum Oscillating in a Stream

The effect of the suction that the vortices in status nascendi exert upon solids is well shown by the experiment with pendulums oscillating in a stream of water or air, described by the author in " L'Aérophile," January, 1911.

If we immerse, orthogonally to the direction of a slowly moving current of water, a plate of certain thickness in such a way that a part of plate lies above the water, we observe that the water begins to rise and sink periodically in the vicinity of the edge of the plate; an increase of pressure at one of the edges corresponds to a decrease of pressure at the other edge and *vice versa* (Fig. 131).

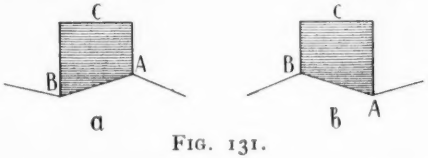


FIG. 131.

Each decrease of pressure is accompanied by the formation of an eddy. At a certain moment the forming eddy detaches itself from the obstacle and, speedily describing a curved trajectory, takes its place in the double row of alternate eddies behind the obstacle, as shown on Fig. 132.

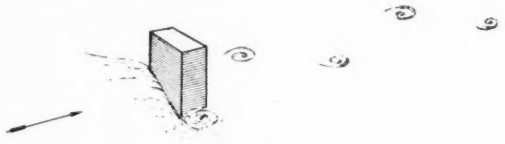


FIG. 132.

The double row of alternate eddies, observed on the surface of a liquid behind a cylinder, was previously observed and sketched by Leonardo da Vinci, and, many centuries later, photographed by Hele Shaw and Henri Bénard. Photographs obtained by Prof. Bénard, showing long files of several sets of alternated eddies, are particularly interesting.

Mallock pointed out that the vibration of an Eolian harp string is due to these alternate eddies, but he thought that the elastic period of the string must approach the rate of formation of the eddies and he did not study the interaction of cylinders and eddies, nor the way in which the latter are generated.

The periodical interchange of rising and sinking water level already mentioned in the vicinity of the edges of the plate, led the present writer (in 1910) to the study of pendulum motion in water and in air as well. The laws for pendulum motion were found to be:—First, the period of the pendulum is independent of the frequency of the eddies generated when the solid, not necessarily a cylinder, is prevented from oscillating. This result does not concord with Mallock's hypothesis. Second, the period T, if the amplitudes ϕ are not too great, is almost the same as if the pendulum oscillated in a fluid without resistance and the friction of pivots is nil. Third, the amplitude ϕ is approximately determined by equation

$$\phi l/T\,(v-v_o)=A,$$

where v—velocity of the stream, T—period of oscillation, l—length of the equivalent simple pendulum, A—a dimensionless parameter, v_o—a parameter with the dimension of velocity. These parameters depend upon the shape of the pendulum and friction of pivots. The pendulum used in an air stream is shown in Fig. 133.

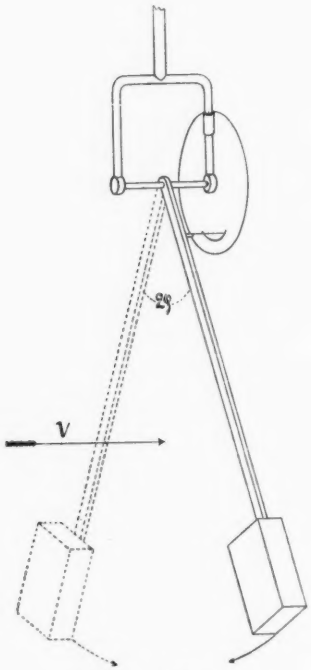


FIG. 133.

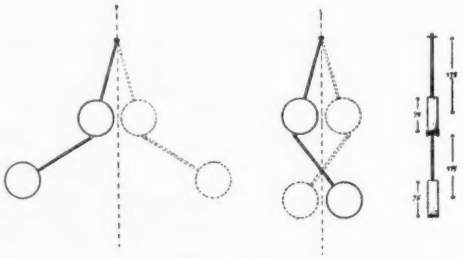


FIG. 134.

The disc, blackened with smoke, served to record the amplitudes. In the double pendulum shown on Fig. 134 two modes of oscillation are possible, but the second one is less stable, so that after an interval, that can be more or less long, we usually obtain the first mode of oscillation.

In a turbulent stream pendulums begin to oscillate automatically. In a more regular stream, in order to avoid having to wait too long, it is sufficient for setting the pendulums in motion to give them a small preliminary oscillation.

15. *Autorotation of Projectiles and on the Role of Moment of Inertia in Some Cases of Autorotation*

We shall now add a few words to what has already been said on autorotation in sections 1 and 5.

When observing the flight of a non-stabilised projectile, sent forth by a trench cannon, the author came to the conclusion that one has to deal in this case also with a phenomenon of autorotation. He proved that it is actually so by introducing the model of such a projectile, or that of a non-stabilised airship, into an air stream and showing that it can be set in autorotation in both senses and for any relative position of the axis and the air velocity (Fig. 135).

FIG. 135.

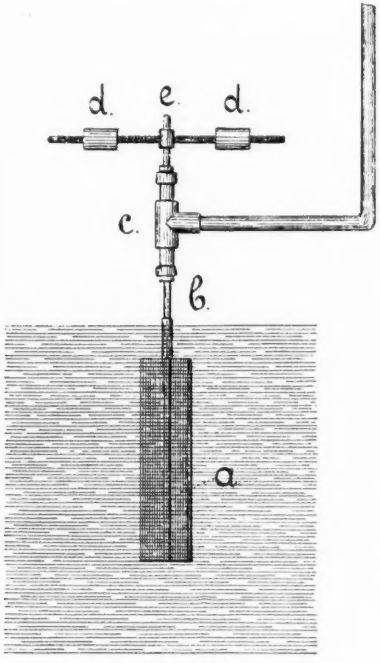


FIG. 136.

The author also tried to repeat in water the experiment of autorotation of a rectangular plate (Fig. 76) and was surprised to find that no autorotation could be observed in a stream, the speed of which was 50 cm. per second.

An opportunity was afforded to apply corollary three of the fundamental theorem of dimensional analysis. In the case under consideration the negative result of the experiment with a rectangular plate could not be ascribed to the influence of viscosity, as the value of the Reynolds number was the same in the water and the air experiments. There only remained to suppose that this phenomenon depends either upon the moment of inertia of the plate, or the compressibility of air. In making the first of these hypotheses and applying formula (3) of section 10, we have

$$nr/v = f(c/\rho r^5)$$

where n is the number of revolutions in unit time, r a linear dimension of the

plate, v the relative velocity, ρ the density of the fluid, c the moment of inertia of the plate, and f is an unknown function.

It seemed at first that by increasing the moment of inertia of the plate proportionally to the density of the fluid we could succeed no better in setting the plate in autorotation, as the position of the plate remained stable, normal to the direction of the current.

However, in order to subject this hypothesis to the test of experiment, the author constructed the apparatus shown in Fig. 136.

The experiment made in the hydrodynamic laboratory (Fig. 13) shows that when the moment of inertia is increased sufficiently, the rectangular plate rotates in a stream of water as well as in an air stream.

This type of autorotation is determined, as has already been explained (see p. 304), by a decrease of pressure behind the edge a, when the plate takes the position shown in Fig. 137 I. When the rotating plate is in the position shown

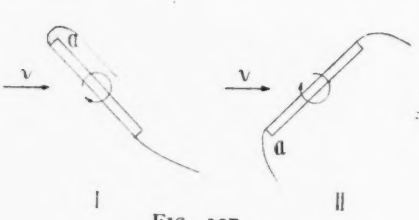


FIG. 137.

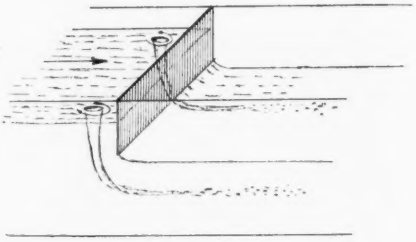


FIG. 138.

on Fig. 137 II, the decrease of pressure in the vicinity of the edge a is less, and it is this difference which determines the autorotation and a force orthogonal to the relative stream.

The moment of inertia of the plate served to *accentuate* and to accumulate the impulses given to the plate when it takes the position I of Fig. 137, and to overcome the resistance to the rotation of side plate in other positions.

The problem of stability of such rectangles and that of aeroplanes is closely connected with fluctuations of the additive mass of fluid.

16. *Vortices Astride Obstacles*

In order to visualise the motion of water in the channel of the hydrodynamic laboratory (Fig. 13) coloured jets and drops of the same density as water were used. Flow patterns with air bulbs were also obtained in the following way. In the two corners between the walls of the channel and the sluice gate (Fig. 14), vortices like those shown on Fig. 138 were formed.

At a certain distance behind the sluice gate the initial more or less regular motion degenerates into turbulent motion and the air drawn in by the eddies forms a multitude of small bubbles which are carried along the walls of the channel. Traces of such air bubbles are seen in Figs. 139 and 140, obtained with two different methods of lighting.

In Fig. 139 the sun's rays are directed at right angles to the free surface of the water by a mirror placed on the glass roof of the laboratory. Fig. 140 was obtained by placing in the water a second mirror inclined at 45° which sent the sun's rays through the water to the photographic apparatus. This way of lighting is analogous to the one used in obtaining advertisements illuminated by daylight in streets with high buildings on both sides and is applied to direct sunlight into the windows of dwellings looking out upon closed yards.

Figs. 139 and 140 show that in front of a square plate placed close to the glass wall of the channel, several vortices are formed. These vortices are also represented diagrammatically on Fig. 141.

By comparing Figs. 142 and 138, we notice the analogy between these vortices and those formed in front of the sluice gate.

It is the action of such vortices that produces the hollows around stones on the seashore and also in snow at the bottom of a tree trunk, and the furrows in the layer of lycopodium powder in aerodynamic flow patterns given in section 6.

In front of the obstacle these eddies are at right angles to the stream, and behind the obstacle their " free ends " first follow the streamlines and then disappear in the turbulence like small streams in sand.

FIG. 139.

We may call such eddies astride obstacles, which cannot exist independently of the latter, " contiguous eddies " or " adjoined eddies " to distinguish them from " free eddies " which either form closed curves across the fluid or begin and end on its boundaries.

We have already mentioned another category of adjoined eddies in section 3 (Figs. 36 and 38).

The author made a special apparatus to obtain " contiguous eddies " isolated from the bottom. The stream was produced by a screw fan and flowed through a honeycomb consisting of a system of orthogonal plates as shown on Fig. 143.

Two strong eddies, in opposite rotation directions, can be produced in this way in front of an obstacle.

FIG. 140.

17. *The Airscrew and Aerofoil Vortex Theory*

The eddies adjoined to an aerofoil were described by Osborne Reynolds as long as fifty-seven years ago in the following terms:—" Having noticed that the action of the screw propeller was greatly affected when air was allowed to descend the blades, the author was trying what influence air would have on the action of a single vane, when a very singular phenomenon presented itself; the air, instead of rising in bubbles to the surface, arranged itself in two long horizontal columns behind the vane. There was evidence of rotating motion about

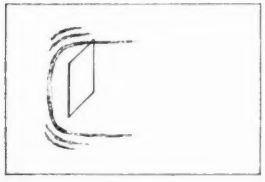


FIG. 141.

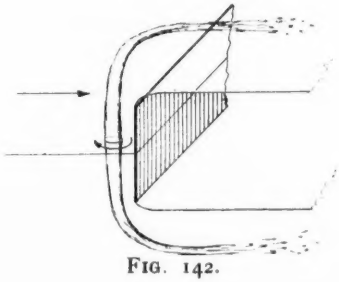


FIG. 142.

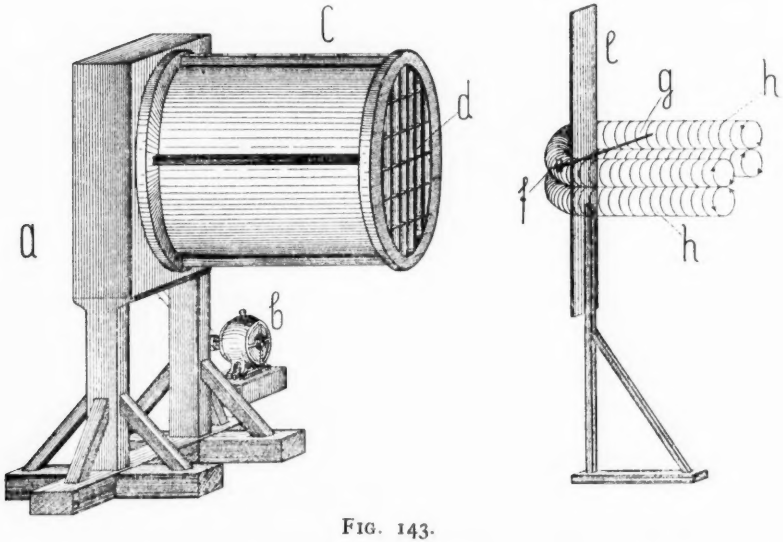


FIG. 143.

these airlines. It was evident, in fact, that they were the central lines of two systematical eddies. That there should be eddies was not surprising, but eddies had always been looked upon as a necessary evil which besets fluid motion as a source of disturbance, whereas here they appeared to be the very means of systematic motion." . . . " Two parallel bands, such as those which follow the oblique vane, could progress if they were infinitely long, but if not, they must be continually destroyed from the ends. Those which follow the oblique vane are continually dying out at one end, and being formed again at the other " (" On Vortex Motion," Proceedings of the Royal Institute of Great Britain, February, 1877; papers Vol. I, pp. 187/191)

Supposing that the motion of the screw propeller is uniform, and that the motion of the fluid is steady with regard to moving axes invariably connected with the screw, the author applied to this problem the dynamical equations under the form

$$\partial H/\partial x = 2(\zeta v' - \eta w')$$
$$\partial H/\partial y = 2(\xi w' - \zeta u')$$
$$\partial H/\partial z = 2(\eta u' - \zeta v')$$
$$H = \tfrac{1}{2}(q'^2 - q_1^2) + \int dp/\rho - U \quad . \quad . \quad . \quad . \quad (1)$$

where q' is the velocity of a fluid particle relative to the moving frame at a point (x, y, z) and q_1 the velocity of the same point considered as invariably fixed to the moving frame.

The second parts of these equations have the same form as in a permanent motion with regard to fixed axes, with the difference that the relative speeds (u', v', w') are substituted for absolute speeds, whereas the eddies (ξ, η, ζ) of the absolute motion continue to figure in the formulæ. We can further apply textually the reasoning of Sir Horace Lamb in the case of steady motion ("On the Conditions for Steady Motion of a Fluid," Proc. London Math. Soc., IX, 91, 1878; Hydrodynamics, fourth edition, p. 235).

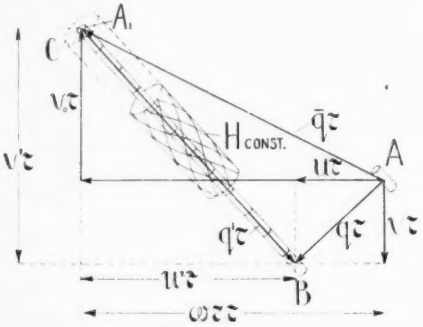


FIG. 144.

It follows from equation (1) that

$$u'(\partial H/\partial x) + v'(\partial H/\partial y) + w'(\partial H/\partial z) = 0$$
$$\xi(\partial H/\partial x) + \eta(\partial H/\partial y) + \zeta(\partial H/\partial z) = 0$$

so that each of the surfaces K=const. contains both streamlines and vortex lines. If further δn denote an element of the normal at any point of such a surface, we have $\partial H/\partial n = q'w \sin\beta$ where q' is the relative vorticity, w the vorticity and β the angle between the streamline of the relative motion and the vortex line of the absolute motion at that point.

Hence, the conditions that a given state of motion of a fluid may be a possible state of steady motion are as follows. It must be possible to draw in the fluid an infinite system of surfaces each of which is covered by a network of streamlines and vortex lines, and the product $q'w \sin\beta\delta n$ must be constant over each such surface, δn denoting the length of the normal drawn to a consecutive surface of the system.

We note that in a domain where H=const., or when a surface H=const. is reduced to a line, we have the condition $\sin\beta = 0$, *i.e.*, the streamlines in the relative motion coincide with the vortex lines of the absolute motion. Fig. 144 gives a geometrical interpretation of these conditions. It follows from this

discussion that, although vortices are continually generated at one end and destroyed at the other, we have the impression that the vortex system keeps an invariable configuration with regard to the axis fixed in the screw and moving with it. This reasoning can obviously be applied to any vortex system adjoined or contiguous to a body, for instance, to those considered in the preceding section 16. Osborne Reynolds' experiments mentioned at the beginning of this section lend experimental confirmation that the conditions stated above are necessary and sufficient in this case.

The author's theory just recalled has provided an explanation of the way in which a vortex system is continually regenerated and keeps an invariable configuration with regard to a moving body. This fundamental result being once established the author was able to apply directly Lord Kelvin's theory of circulation and the results thus attained proved very useful in the elucidation of several important points of the airscrew vortex theory, as will be seen from examples hereunder.

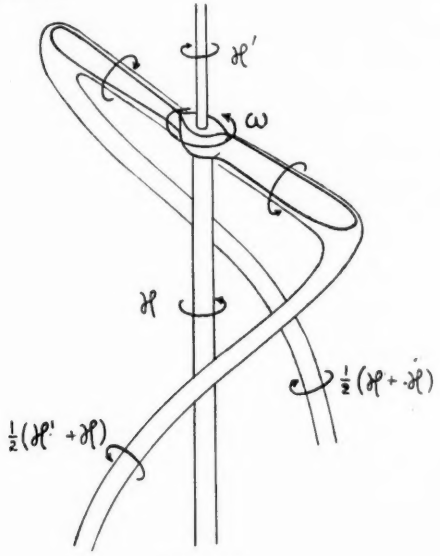


FIG. 145.

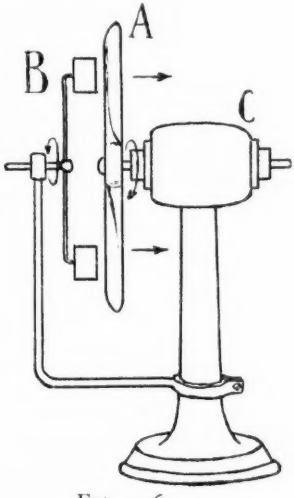


FIG. 146.

The author published two papers on these matters in summer 1912 and later, returning to the standpoint of the first of the said notes, a statement of his ideas in the fourth issue of the " Bulletin of Koutchino " (November, 1912).

Fig. 145 represents the author's initial drawing of vortex configuration.

The author introduced a vortex tube in front of the screw in agreement with experiments he had already made. When studying with an anemometer the distribution of velocities in front of the screw, he had observed a negative circulation, although, in fact, a very weak one. He gave the following explanation of this observation (fourth " Bulletin of Koutchino," page 80):—The relative speed above and in the close vicinity of a moving aerofoil exceeds the speed of the latter and has an opposite sense; hence the absolute velocities above the aerofoil are directed in the sense opposite to its motion.

The author recently obtained similar results by placing in front of a stationary airscrew a swivel, the vanes of which were orthogonal to the screw disc. If the swivel is brought sufficiently near to the screw blades and so that the axes of

the screw and of the swivel coincide, the blades of the swivel are observed to revolve in the sense opposite to that of the screw.

It must be noted, however, that in an irregular wind, provided the resistance is proportional to the square of velocity, the anemometer could register a mean speed different from zero and the blades of the swivel could revolve, even in the absence of circulation, as may easily be understood, by considering the accompanying sketch (Fig. 147).

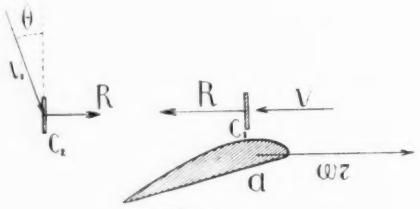


FIG. 147.

The author fully shares the opinion recently expressed by Prof. G. I. Taylor in his paper " Rotational Inflow Factor in Propeller Theory " (Technical Report of the Advisory Committee for Aeronautics, 1921-22, R. 765, May, 1921).

In order to annul the vortex placed in front of the screw propeller, it is sufficient to place in Fig. 145 $K'=0$. By admitting that this was so, the author obtained the results described in the papers mentioned above and summarised hereunder.

If it is assumed that the free ends of the adjoined eddies satisfy the condition

$$\xi/u'=\eta/v'=\zeta/w' \quad . \quad . \quad . \quad . \quad . \quad (2)$$

we can write according to equation (1)

$$p+\tfrac{1}{2}\rho q^2-\rho\omega ru+\rho Vw=p_0+\tfrac{1}{2}\rho q_0^2+\rho Vw \quad . \quad . \quad . \quad (3)$$

The terms on the left hand side of this equation relate to a point A, situated immediately behind the screw disc; those of the right hand side to a point B, situated immediately above the screw disc and the point A.

q is the absolute velocity, u the component of the absolute speed orthogonal to the axis and the radius, $w=w_0$ is the component of the absolute speed parallel to the axis of the screw, ω the angular speed and V the propulsion speed of the screw, r the distance of the point considered from the axis.

Let us suppose by first approximation, that velocity u is nil in front of the screw and that behind the latter it has a constant value for a given r. The circulation around the axial vortex, or, what is the same, the sum of circulation around all the blades of the screw, is then $K=2\pi ru$.

The idea of considering points A and B as very close to each other, but placed at different sides of the screw disc, proved useful. It allows us to admit that the velocity w has approximately the same value at points A and B and several interesting consequences can be deduced therefrom. First of all we obtain from (3)

$$(p+\tfrac{1}{2}\rho q^2)-(p_0+\tfrac{1}{2}\rho q_0^2)=\rho\omega ru=\rho n\mathrm{K} \quad . \quad . \quad . \quad (4)$$

where n is the number of revolutions of the propeller in unit time and K is the circulation along the blades of the screw. By assuming that the circulation remains the same along the blades, by multiplying the two parts of equality $\omega rn=n\mathrm{K}$ by the rate of the afflux through the screw disc, $M=\rho\pi r^2w'$, and applying the theorem of angular momentum, we find as expression of torque power

$$T=Mn\mathrm{K} \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

To determine the circulation K the author applied the following reasoning. Let us replace the free ends of the isolated adjoined eddies by a thin layer of spiral eddies enveloping uniformly the cylindrical " vena contracta " beyond the screw disc. The pressure must be the same on both sides of this layer. Hence, according to equations (1) and (2), we have

$$u^2 - 2\omega r u + w'^2 - V^2 = 0$$

and therefore

$$\mathrm{K}n = \omega r u = \omega^2 r^2 \{ 1 - \sqrt{[1 - (w'^2 - V^2)/\omega^2 r^2]} \} \quad . \quad . \quad (6)$$

If this formula is applied to the actuator, it must be admitted, as has been explained in section 4, that $n \to \infty$, $h \to 0$, whilst the product nh remain finite, $nh = w'$.

From (6) we get, since $(w'^2 - V^2)/\omega^2 r^2$ tends to zero, that

$$\mathrm{K}n = \tfrac{1}{2}(n^2 h^2 - V^2) \quad . \quad . \quad . \quad . \quad . \quad (7)$$

the elimination of Kn between (5) and (7) leads to equation (7) already considered in section 4.

Formula (9) given below, which is often used nowadays, can easily be deduced from equations (3) and (4). Going back to formula (3), by taking in account that

$$q^2 = u^2 + w^2, \quad q_0^2 = w_0^2 = w^2,$$

we have

$$p - p_0 = \rho u (\omega r - \tfrac{1}{2}u) = \rho [n\mathrm{K} - \tfrac{1}{2}(\mathrm{K}/2\pi r)^2].$$

Now, applying the theorem of linear momentum and designating under dQ the propelling force exerted on the blades' elements, the distance of which from the axis is r and the breadth dr, we can write

$$dQ = [(p + \rho w^2) - (p_0 + \rho w_0^2)]\, 2\pi r dr = \rho [n\mathrm{K} - \tfrac{1}{2}(\mathrm{K}/2\pi r)^2]\, 2\pi r dr$$

or, since $(\mathrm{K}/2\pi r)^2$ is comparatively small,

$$dQ = [(p + \rho w^2) - (p_0 + \rho w_0^2)]\, 2\pi r dr = \rho n \mathrm{K} 2\pi r dr \quad . \quad . \quad (8)$$

By eliminating ρnH between (4) and (8), we find

$$dQ = [(p + \tfrac{1}{2}\rho q^2) - (p_0 + \tfrac{1}{2}\rho q_0^2)]\, 2\pi r dr \quad . \quad . \quad . \quad (9)$$

The gradient of traction along the blades is therefore easily measurable with Pitot tubes. Such measurements were effected by Stanton and Marshall (1918), Fage and Howard (1921), Lock and Bateman (1923).

When developing the theory set forth in the preceding pages, the author had no need to apply the Kutta-Joukovsky theorem, and it was, on the contrary, the formulæ established by him which gave a complete solution of the question as to how this theorem can be applied in this case and in that of aerofoils.

18. Remarks Upon a Few Apparata

The apparatus represented in Fig. 148 was constructed with a view to its being utilised for two purposes. First of all for measuring the circulation around bodies placed in the wind channel, secondly for measuring the variation of the quantity $p + \frac{1}{2}\rho q^2$ in the disturbed zone behind the obstacles. The study of dissipation of energy which determines the resistance of fluids, is certainly very important.

The author obtained interesting results concerning the repartition of $p + \frac{1}{2}\rho q^2$ behind a disc in the wind channel. Mention is made thereof on page 112 of the third " Bulletin of Koutchino " (1909) but, being engrossed in other researches, these results were not published.

Fig. 149 shows an aerodynamic torsion balance for measuring the resistance of bodies of small size in a wind tunnel.

Figs. 150, 151 and 152 show the apparata used for measuring pressures and for calibration of instruments used for measuring air velocity, as well as the velocity of the wind determined in the hall of the laboratory by the rotation of the lever of the apparatus shown on Fig. 150.

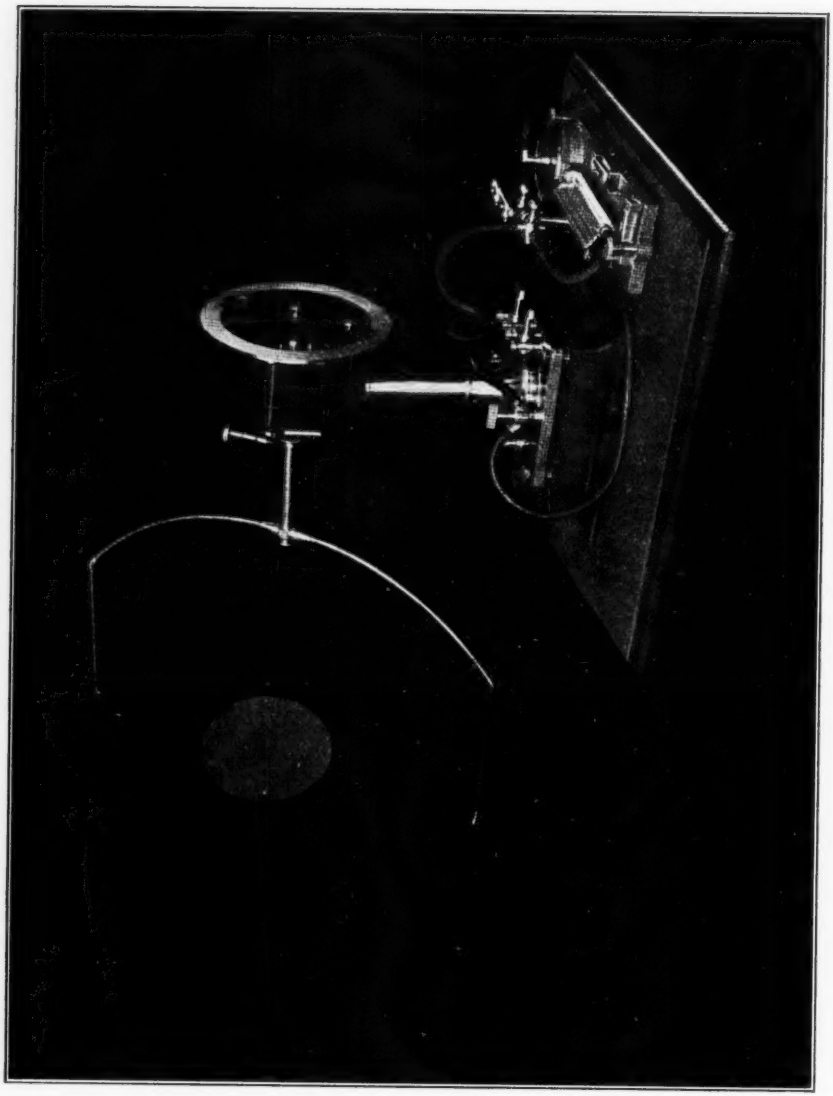


FIG. 148.

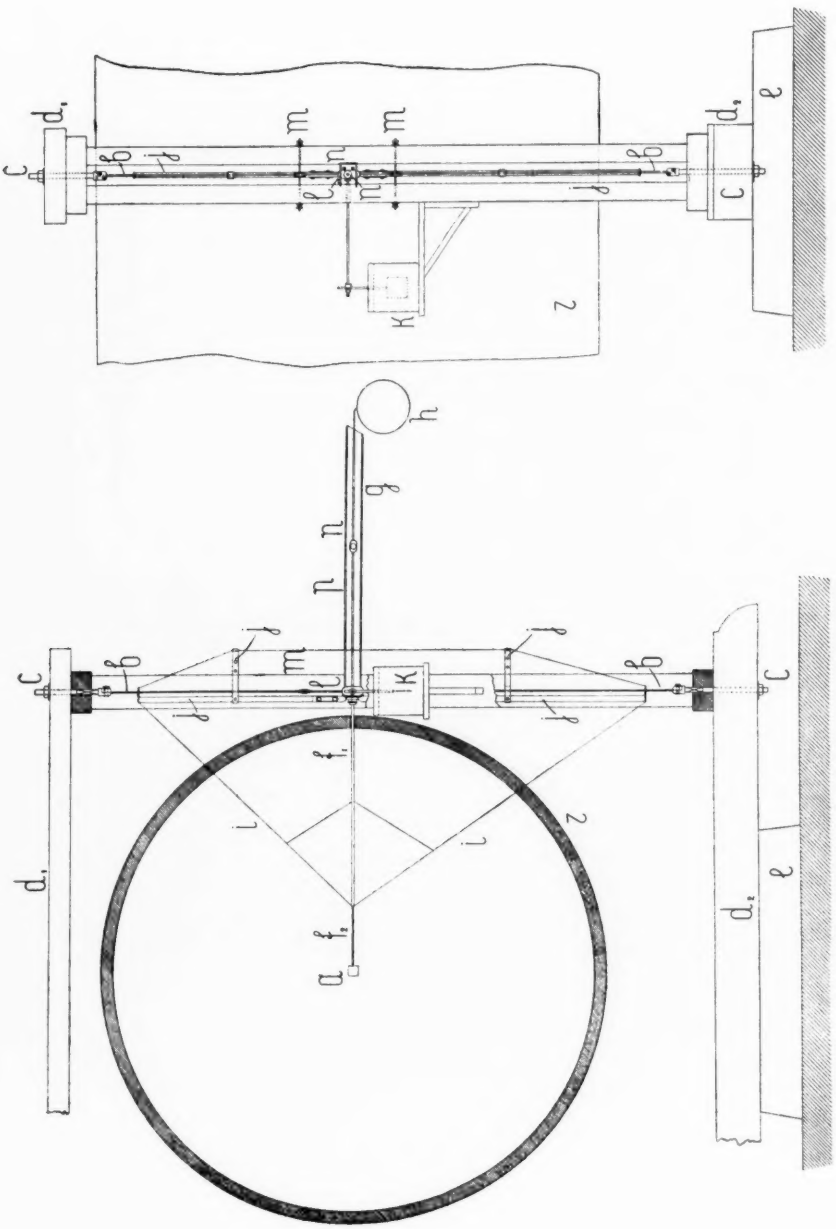


FIG. 149.

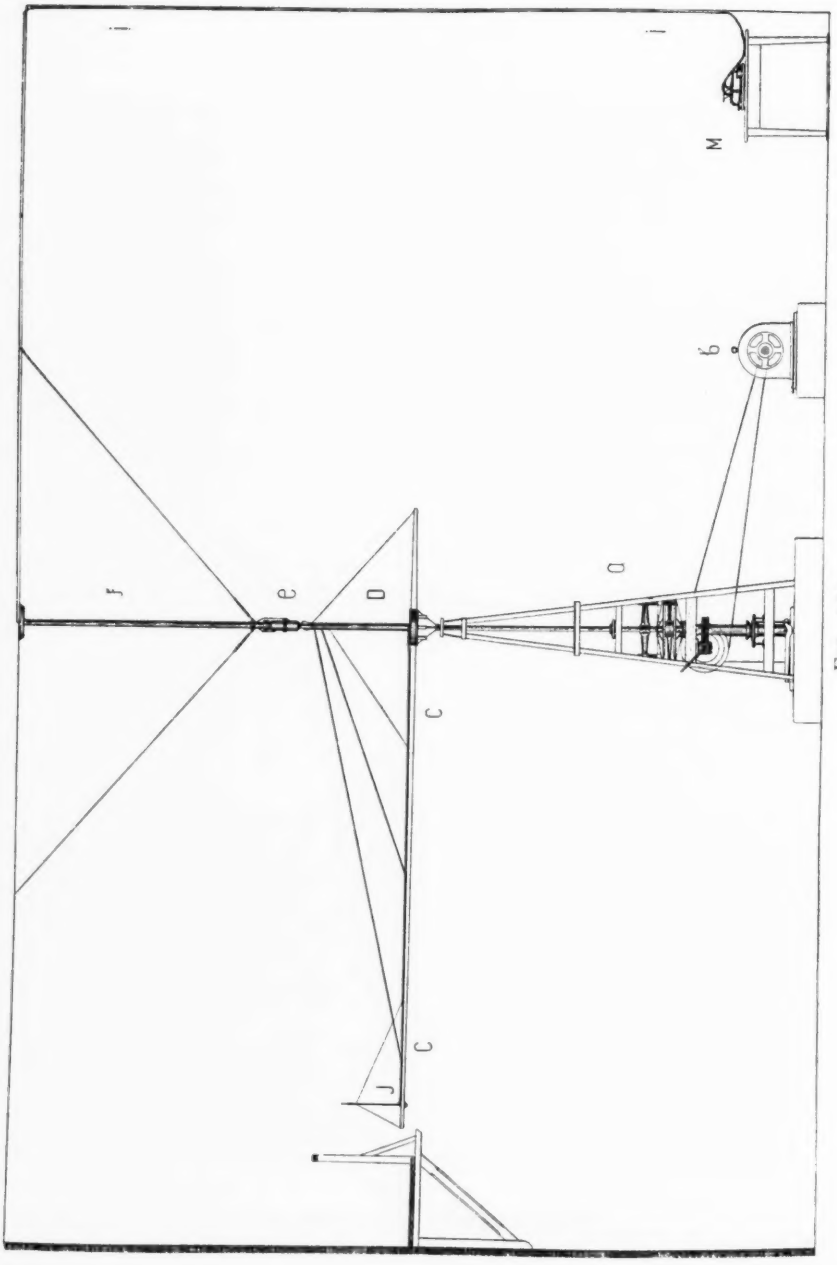


FIG. 150.

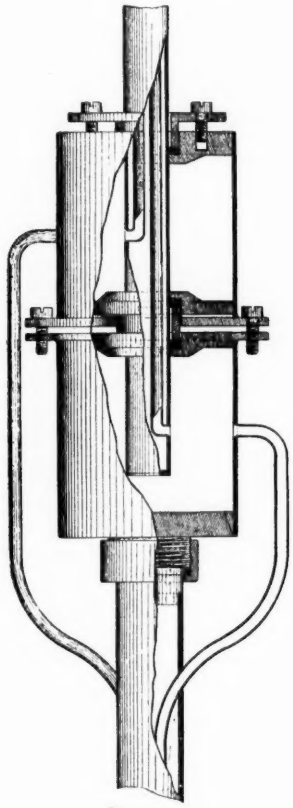


FIG. 151.

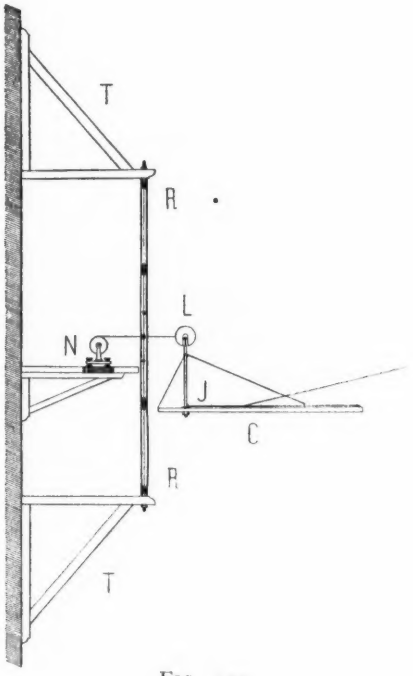


FIG. 152.

19. *Contraction of Gaseous Jets and Resistance of Compressible Fluids*

Let us suppose that a gas, subject to the adiabatic law, flows steadily out of a wide vessel or out of one furnished with a moving piston which keeps up constant pressure, and that this vessel is or is not fitted with a convergent-divergent opening (Fig. 153 *a* and *b*), according to the value of ratio of the pressures inside and outside the vessel being less or more than 1.9.

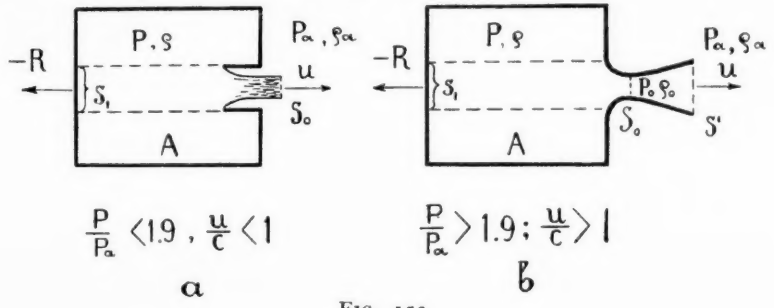


FIG. 153.

By applying the theorem of linear momentum and the equation of energy, we can write

$$R/S_1DV=(p-p_a)/DV=S_0/S_1=f(V/c) \quad . \quad . \quad . \quad (1)$$

where

$$f(V/c)=f_1(V/c)=(1/\gamma)(c^2/V^2)\left[\left(\tfrac{1}{2}(\gamma-1)(V^2/c^2)+1\right)^{\gamma/(\gamma-1)}-1\right] \quad . \quad (2)$$

if $V/c<1$, and

$$f(V/c)=f_2(V/c)$$
$$=\{(\gamma^2-1)/4\gamma^2\}^{\frac{1}{2}}\{(\gamma+1)/2\}^{1/(\gamma-1)}$$
$$\{1+[2/(\gamma-1)](c^2/V^2)\}^{\frac{1}{2}}\left[1-\left\{\left[(\gamma-1)/2\right](V^2/c^2)+1\right\}^{\gamma/(\gamma-1)}\right] \quad (3)$$

if $V/c>1$.

In these formulæ R is the reaction exerted upon the vessel by the gaseous jet, D the rate of discharge per unit area of the vena contracta equal to $(\rho_a V)$ or $(\rho_0 c_0)$ according to the ratio V/c being lesser or greater than unity, c is the velocity of sound for the outside pressure p_a and density ρ_a, V is the outflow velocity after a complete expansion. The meaning of the other signs which figure in these formulæ is evident from Figs. 153.

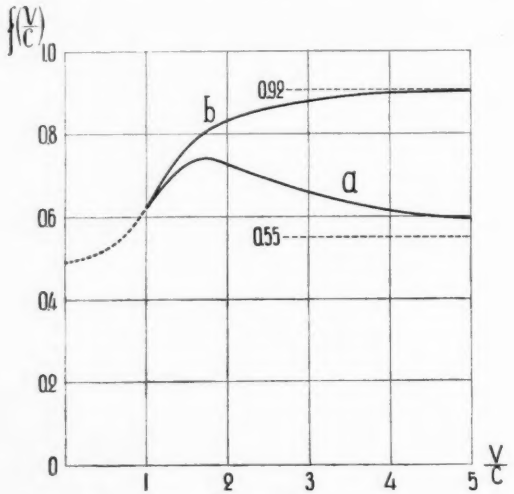


FIG. 154.

The graph of the function $S_0/S_1=f(V/c)$ is represented on Fig. 154 by curve a. It is interesting to note that there exists a certain analogy between this curve and the one which gives the variation of the coefficient of resistance of pointed projectiles in function of ratio V/c.

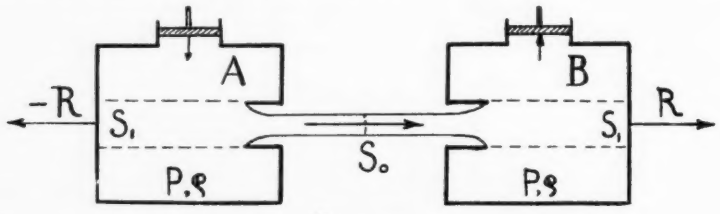


FIG. 155.

To pass from the theory of contraction of a gaseous jet to that of resistance of compressible fluids, consider first Fig. 155.

The gas flows out of vessel A and, after complete expansion, compresses again in vessel B; it then flows out through lateral apertures. Fig. 155 can be replaced by that of Fig. 156.

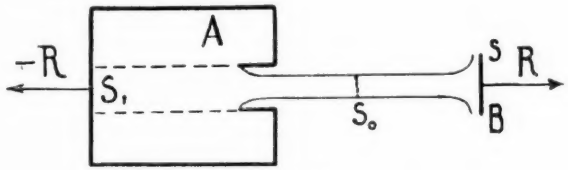


FIG. 156.

The pressure R exerted on vessel B of Fig. 155 will be

$$R=-(-R)=\rho_a S_1 V^2 f_1(V/c).$$

In the case shown on Fig. 156 the area of surface B will be somewhat greater and the mean pressure somewhat less than in the case shown on Fig. 155. The pressure per unit area will be the same as in vessel B (Fig. 155) only in the middle of plate B (Fig. 156).

If the outflow velocity V of jet exceeds that of sound, a shock wave C will arise in front of obstacle B, as shown on Fig. 157.

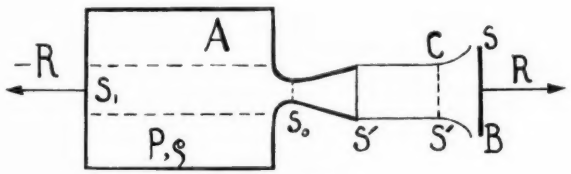


FIG. 157.

Applying in this case the theorem of linear momentum, we can write

$$R/S\rho_a V^2=S'/S=(p_2-p_a)/\rho V^2=f(V/c) \quad . \quad . \quad . \quad (4)$$

and, according to Lord Rayleigh's formula, we find

$$f(V/c)=f_3(V/c)$$
$$=\gamma^{-\gamma/(\gamma-1)}\{(\gamma+1)/2\}^{(\gamma+1)/(\gamma-1)}\{1-[(\gamma-1)/2\gamma](c^2/V^2)\}^{-1/(\gamma-1)}$$
$$-(1/\gamma)(c^2/V^2) \quad . \quad . \quad . \quad . \quad . \quad (5)$$

provided $V/c>1$.

The graph of function $S'/S=f_3(V/c)$ is represented on Fig. 154 by the curve b. This curve reminds that which represents the variation of resistance coefficients of blunt cylindrical projectiles in function of ratio V/c.

The analogy mentioned above between curve a of Fig. 154 and the drag-resistance curve of pointed projectiles, acting as inverted laval twyers, suggested to the author (in 1915) the hypothesis that besides motions with formation of shock waves, there can exist reversible motions with " contraction " of the jet as shown on the tentative outlines of Fig. 158.

In the centre of plate B (Fig. 158) the pressure may be the same as in vessel A, *i.e.*, p_1, but the mean pressure of the whole plate will be

$$R/S\rho_a V^2=S_0/S_1=S'/S=f_2(V/c) \quad . \quad . \quad . \quad . \quad (6)$$

provided the condition

$$S_0/S_1=S'/S, \quad . \quad . \quad . \quad . \quad . \quad (7)$$

where S' and S are respectively the section of the jet and the area of the plate (Fig. 158), is fulfilled. When considering resistance as the inverse problem of the reaction of a gaseous jet, the hypothesis that section S, defined by the equation (7), coincides with the medial section of the projectile, seems to be in agreement with experiment (see Fig. 159, curve *a*).

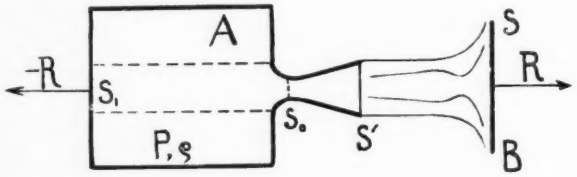


FIG. 158.

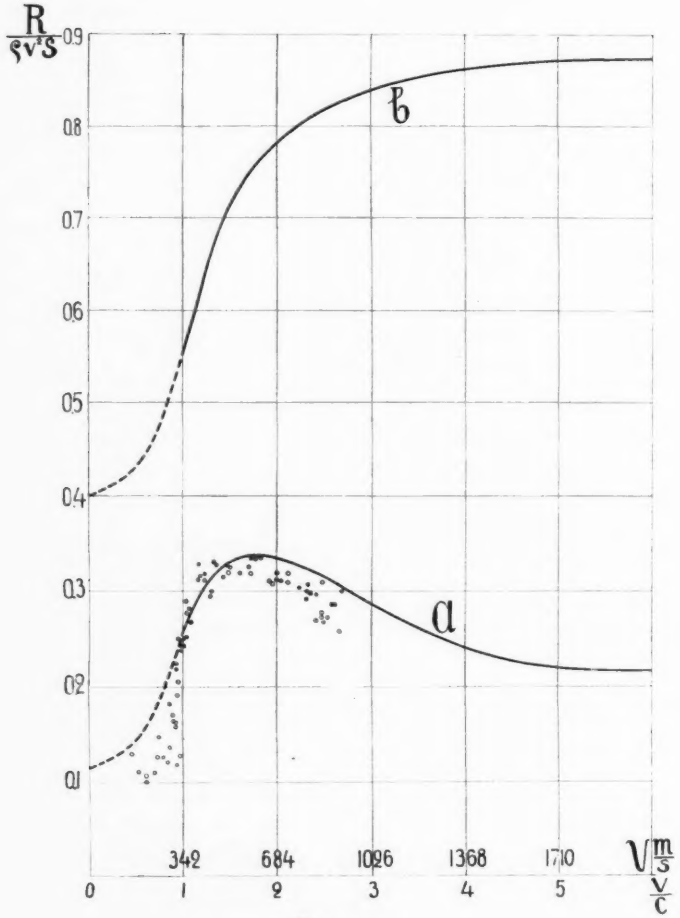


FIG. 159.

To form an approximate idea of the total resistance of the projectile, without having recourse to rigorous calculation of the distribution of speeds and pressures, we must add a few supplementary remarks.

In a perfectly incompressible fluid, if no shock is produced, the resistance due to inertia is zero, as the energy of the body cannot be transmitted to the fluid. Hence the streamlines will join behind the body and the pressure at the front and back will balance.

In a compressible fluid, resistance R will not be zero, as a general rule, as the energy of the body can be transmitted to the surrounding fluid in the form of waves. In the limiting case only the pressure due to sole inertia will be balanced.

According to this and provided section S in formula (6) expresses the area of medial section of the body, the resistance R can be expressed thus

$$R/S\rho_a V^2 = f(V/c) - \tfrac{1}{2} + k \quad . \quad . \quad . \quad . \quad (8)$$

where, in case of an actual fluid, a coefficient k, characterising the resistance due to friction and shocks, must be added to the right hand part.

Curve *a* of Fig. 159 was calculated according to formulæ (8), (2), (3), giving to coefficient k the value 0.114, which corresponds to the coefficient which figures in Malevsky's Ballistic.

The points indicated on Fig. 159 express the results of experiments made in several countries, which allowed Siacci to draw his well-known curve.

Curve *b* on Fig. 159 was calculated according to formulæ (8), (2), (5), giving to coefficient k the value 0.4. This curve corresponds to blunt cylindric projectiles.

Alternative cases may be also considered.

20. *Rockets and Rocket-Gun*

Fig. 160 represents General Pomortzeff's pneumatic rocket. This rocket is formed of a steel tube, one end of which is closed and the other forming a convergent-divergent ajutage. The orifice of this ajutage is closed by a stopper which by means of a special contrivance can be instantly removed at any given moment. In the experiments carried on at the Institute of Koutchino, air was compressed in these rockets under 100-120 atmospheres and either benzine or ether was introduced therein to form an explosive mixture, or simply a certain quantity of gunpowder. General Pomortzeff's rocket was fitted with a stabilising cylinder, as shown on Fig. 160.

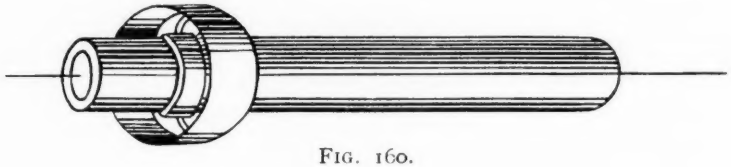


FIG. 160.

The author developed the theory of General Pomortzeff's rocket and constructed for the study of this and other types of rocket, three apparata. The first one was a kind of ballistic pendulum, the second one, a dynamometer recording the action in time, and the third one was a " ballistic wheel " four metres in diameter. The construction of the last of these apparata was not completed before the author's departure from Russia. The author also studied rockets in free flight in order to test his theory. He showed that the total impulse received by the rocket is, at a first approximation, independent of the area of the aperture, hence the rocket can be a cylindrical tube open at both ends without any ajutage, provided a sufficient initial pressure can be obtained under such conditions. This result led the author to construct, in summer 1916, a small trench-

gun which can be considered as a rocket, the shell of which remains fixed, whilst the useful weight alone, *i.e.*, the projectile, is thrust forward.

Fig. 161 shows the design of this rocket-gun, which is simply a cylindrical tube open at both ends. The projectile *A* was shot out, not by compressed air,

FIG. 161.

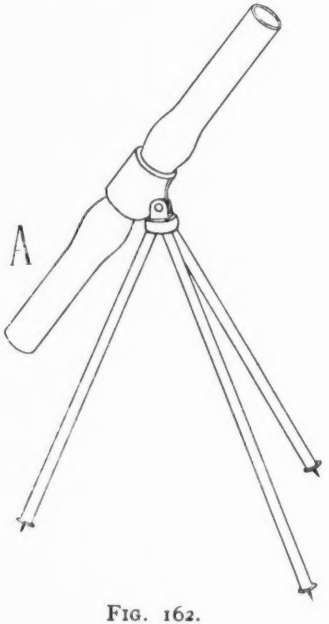


FIG. 162.

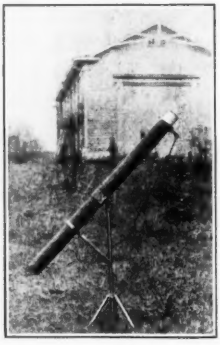


FIG. 163.

as in Pomortzeff's rocket, but by the explosure of gunpowder contained in a cartridge, *B*. The weight of the gun was 8 kilograms, the weight of the projectiles 3 and 4 kilograms. Charges of 300 and 400 grammes of gunpowder respectively shot out these projectiles at above 320 metres. The charge was made to explode by means of an electric detonator. The recoil was zero, the gun was never seen to fall or to deviate noticeably from its position after the shot. This result is

very remarkable if we consider that the weight of the projectile was more than half that of the gun.

The steel tube *A* was only useful with the charges used, for a limited number of shots, from 10 to 15. After each shot, the tube expanded and, after a certain number of shots, took the shape indicated in Fig. 162. This deformation was obviously a result of the extremely small weight of the gun. Fig. 163 is a photograph of the rocket-gun in the primitive form given to it by the author.

In the gun just described, the projectile is thrust forward by the reaction of the gaseous jet produced by detonation of the gunpowder contained in the cartridge.

The Davis gun, used on aeroplanes during the war (*La Nature*, 2 Dec., 1916), also solved the problem of the recoilless gun, but by thrusting in the direction opposite to that of the projectile a mass of lead approximately equal in weight to that of the projectile. The functioning of the Davis gun can be compared to that of two ordinary guns, backed against each other and shot simultaneously. It will be explained in section 23 of next chapter that there exists a wider difference between the classical gun and the author's rocket-gun.

CHAPTER IV.

RESEARCHES PURSUED WITHIN THE PERIOD 1919–1934

From the end of 1918 the author continued his researches abroad, working for a few months in Denmark, and afterwards in France. Being at first without a laboratory he concentrated upon theoretical investigations. Later he was enabled to carry on in Paris theoretical research parallel with experimental work. Some researches pursued during this period are summarised in this chapter.

21. On the Helmholtz-Kirchhoff Theory of Resistance

When a thin rigid plane is fixed in a fluid in motion, and normal to the direction of flow, we observe near to its edges the formation of a " free " surface, or surface of " slip," which remains well defined for a certain distance from the plane, but degenerates and thereafter vanishes in a whirling and chaotic movement. Experience also shows that the pressure behind the plane is in this case distributed in an approximately uniform manner over its surface, and is less than the pressure in the undisturbed current.

The Helmholtz-Kirchhoff theory, which assumes a free surface extending to an infinite distance, neglects the suction behind the plane. This suction, causing an increment of the velocity on the free surface, must evidently modify the distribution of the velocities on the front face of the plane.

The author studied the case in which (the motion of the fluid being supposed to be parallel to a fixed plane) two planes are disposed, one behind the other, at right angles to the stream, and their edges connected by free surfaces (see Fig. 164).

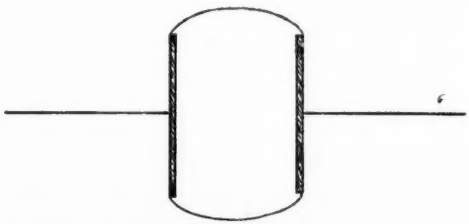


FIG. 164.

The velocity at the free surface is in this case greater than the velocity of the stream. The two plates mutually attract each other, but the resultant pressure of the fluid on the system of the two planes is evidently zero.

The case studied by Kirchhoff (which may be considered as a limiting case, in which the two planes are infinitely apart) should not be inconsistent with the paradox of d'Alembert.

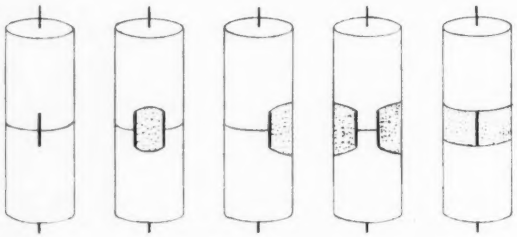


FIG. 165.

The hypothesis of steadiness of motion necessarily leads to the conception of the presence of a second body at infinity. This becomes obvious when considering motion in closed circuit, *e.g.*, on a cylindrical stratum of uniform thickness (Fig. 165). This problem has been recently further discussed by the author's pupil, Dr. C. Woronetz.

In a real fluid, a fictitious plane representing the cumulative effect of friction and of the shocks which, by causing a dissipation of energy, produce the resistance, may be supposed to correspond to the second plane.

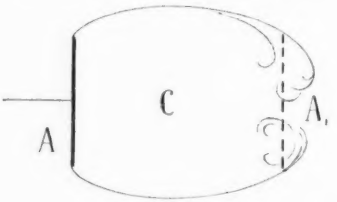


FIG. 166.

Borrowing from experience one single contribution, viz., the intensity of the suction behind the plane, we may calculate the distribution of velocity over the front face, and the total pressure exerted by the stream on the plane.

FIG. 167.

Fig. 167 shows the distance which should exist between the two planes in order that they could be mutually attracted by a force approximately equal to that which a stream of real fluid exerts on a thin plane. This theory was given in the Proceedings of the London Mathematical Society (Série 2, Vol. 19, Part 3, 1919).

In the case of a permanent cavity, filled with air and vapour of water, behind a lamina orthogonal to the stream (Fig. 166), the approximate shape of the cavity can also be calculated by introducing a fictitious plane symmetrical to the first (see dotted line A on Fig. 166) and by applying the theory mentioned above.*

In 1920, at the International Congress of Mathematicians at Strassbourg, and in a paper published in the Proceedings of the London Mathematical Society in 1925, the author extended this theory to the case of two oblique planes placed symmetrically with regard to an axis orthogonal to the stream (Fig. 168).

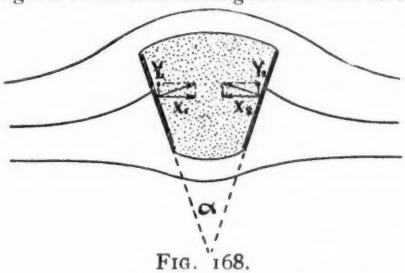


FIG. 168.

The author demonstrated that the motion of the fluid must necessarily be cyclic in this case and that it is possible to calculate the forces acting on the planes (Fig. 168) simply by applying the Kutta-Joukovsky theorem.

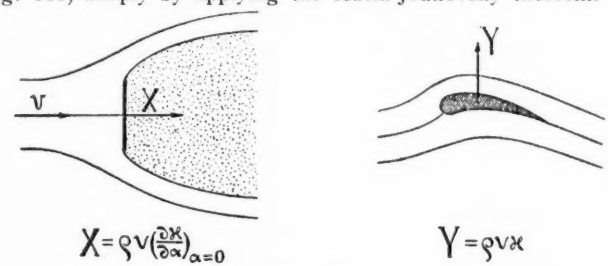


FIG. 169.

This remark allows to establish a rather unexpected analytical analogy (Fig. 169) between the force of resistance in the Helmholtz theory and the sustaining force of Kutta-Joukovsky.

In the case when two oblique planes are parallel to each other (Fig. 170), a problem which was solved by Dr. E. J. C. Poole, the circulation is nil.

FIG. 170.

It can therefore be expected that permanent cavities adjoined to an oblique plane must be more like the Fig. 171*a* than that of Fig. 171*b*.

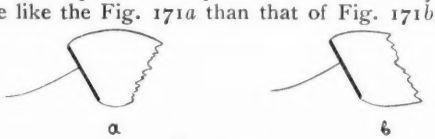


FIG. 171.

* Buseman. Centralblatt für Mechanik. I Band, Heft I, p. 41, 1933.

22. *The Kinetic Energy of the Fluid and the Shape of Moving Immerged Solids*

The kinetic energy of the fluid surrounding a moving body and, therefore, its additional mass, plays an important part in various problems in the mechanics of fluids. Strict calculation of kinetic energy whenever the form of the body is complicated presents considerable difficulties.

The author has demonstrated the following theorem.

When we have two bodies, A and B, so that A can be considered as part of B, we have the inequality

$$T_B + \tfrac{1}{2}\rho v U^2 > T_A \qquad (1)$$

where T_B and T_A are respectively the kinetic energies of the fluid surrounding body B or A when these bodies are moving with velocity U in an infinite mass of liquid which is at rest at infinity; v is the difference between the volumes of the bodies B and A and ρ the density of the fluid. If we compare the kinetic energy corresponding to two tin plates of different shape we have $v=0$ and $T_B > T_A$. For instance, the kinetic energy of the fluid corresponding to a figure of any shape, however complicated (Fig. 172), is always less than that of the fluid surrounding the disc itself; we suppose that in both cases the velocity U forms the same angle with the plane of the plates.

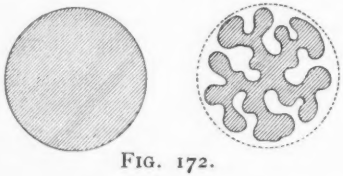


FIG. 172.

The inequality (1) is important as it allows one to allot superior and inferior limits to the unknown kinetic energy of the movement round a solid body of very complicated configuration, when we know kinetic energies of the fluid surrounding inscribed and circumscribed bodies (C.-R. Acad. Sc. t. 144, 1922, p. 212).

23. *Reaction of Gaseous Jets*

In the beginning of 1924 the author had occasion to carry out on a beach near Biarritz several experiments concerning the reaction of gaseous jets, in connection with the matter mentioned in section 20. The jets were produced by explosion within steel tubes of cartridges containing gunpowder. The author gave to such " rockets " the name of " rockets with preliminary combustion."

Those rockets produce in a very simple way powerful impulsive forces and couples which can be applied to any kind of mechanical systems. The elementary theory of the functioning of such rockets was explained by the author in a paper published in the " Mémorial de l'Artillerie Française " (1923), and several rockets were tested by him in order to control this theory by experiment.

One of these rockets is shown on Fig. 173.

The reaction of gases flowing through lateral apertures causes an energetic rotation of the projectile round its axis. The flight of these rockets resembles that of projectiles thrust out by a rifled cannon. Fig. 174 shows the rocket on the launching apparatus.

Fig. 175 represents the apparatus used for an experiment in pile-driving. The head of the pile is adjusted in a steel cylinder in such way that it can slide along it. The reaction of the gas produced by the explosion of the cartridge violently drives the pile into the earth.

The length of the pile was 195 cm. and the part introduced into the cylinder was 50 cm. The diameter of the part of the pile which fitted in the cylinder was 8.8 cm. and that of the part outside the cylinder was 10.5 cm. The inner diameter of the steel cylinder was 9.3 cm.

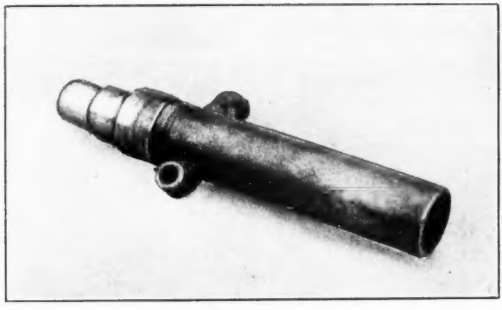


FIG. 173.

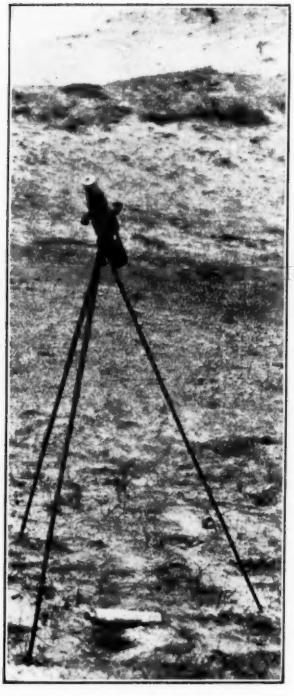


FIG. 174.

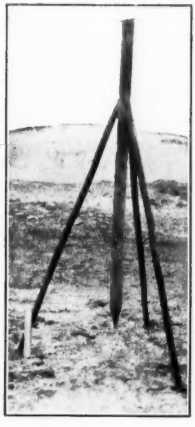


FIG. 175.

The weight of the pile was 12.9 kilograms. A charge of 575 gr. of black gunpowder drove this pile 60 cm. into the sand. Fig. 163 represents a preliminary combustion rocket fixed to a disc and the apertures of which were cut

so as to determine the rotation of the whole system around an axis perpendicular to the main impulse.

The system of Fig. 176 weighed 503 grammes and, launched under an angle at approximately 25° by a charge of 50 gr., fell at a distance of 110 metres, several times rebounding on the wet sand of the beach.

The proper functioning of preliminary combustion rockets depends upon the resistance of the cartridge containing the gunpowder. It is essential that

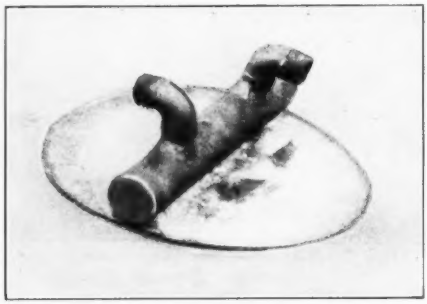


FIG. 176.

burning should take place quicker than the outflow of the gases from the apertures of the envelope of the rocket. It is interesting to note that, when using paper cartridges, it is sufficient to add the thickness of a few leaves in order that the rocket, instead of falling within a few paces of launching apparatus, should fly over several hundred metres.

These experiments were mentioned by the author in a communication to the Congrès International de la Navigation Aérienne, Brussels, 1925.

FIG. 177.

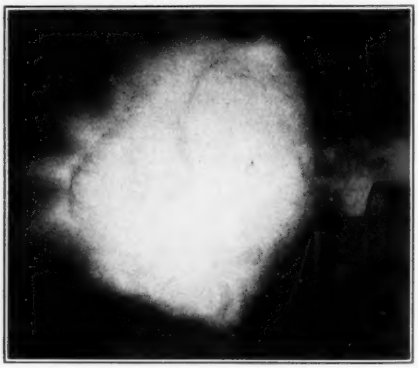


FIG. 178.

The main characteristic of preliminary combustion rockets, and of rocket-guns, described in section 20, is the increase of their efficiency when the ratio of weight of the rocket or of the projectile of the rocket-gun to the weight of the charge decreases. In an ordinary gun it is the opposite that takes place.

Figs. 177 and 178 reproduce two photographs taken at night of the shot of a rocket-gun.

24. *Change of Régime in Fluid Motion and Turbulence*

The aerodynamic spectres and experiments with adjoined eddies (see sections 6 and 16) may suggest that whilst in a laminar motion the eddies of the boundary layer are more or less orthogonal to streamlines, in the transitory régime between a laminar and a turbulent flow, a more suitable configuration is that of a system of vortex tubes in the boundary layer, the axis of which coincides with the streamlines, and that turbulence is due to the absence of any stable eddy configuration in the boundary layer.

In order to illustrate this idea, the author constructed a " model " of change of régimes in fluids and of turbulence.

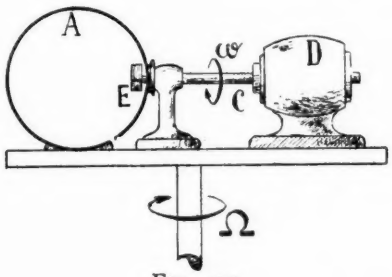
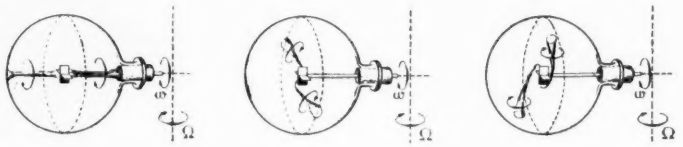


FIG. 179.

A globe filled with water, but containing some air bubbles, may be set rotating around a vertical axis, as shown in Fig. 179. The small motor which imparts steady angular velocity to a small rotor immersed in water, revolves with the globe. The water in the small globe represented in our model a fluid particle and the circle described by the centre of the globe with a speed V represents a streamline. We presuppose that the streamline lies in a plane parallel to a rigid wall and that the small rotor represents the viscosity which causes the fluid particles to rotate.

When there is no rotor at all the fluid is " perfect," and if we start the whole system in motion the water in the globe will describe a circular trajectory, but as long as the effect of friction against the wall may be neglected the water



a b c

FIG. 180.

will not rotate. A straight line of colour, drawn in the water, will remain parallel to itself whilst the globe describes its circular trajectory, the motion will be " irrotational."

Now let us suppose that the angular velocity of the rotor is large and that of the whole system is small; this case will correspond to small Reynolds numbers and the vortex is at right angles to the speed V. The air bubbles are disposed along the axis of the rotor (Fig. 180*a*).

But if the angular velocity of the whole system and consequently the Reynolds number increases, we can observe that, at a certain critical velocity,

the vortex ceases to be at right angles to the speed V of the globe and becomes parallel to it. We thus obtain the curious result that the water rotates at right angles to the axis of the rotor, which maintains its rotation (Fig. 180*b*). This motion, which the author expected to find when devising the apparatus, corresponds to the case in which the eddies of the boundary layer coincide with streamlines. If the angular velocity increases still more, the eddies tend to become parallel to the vertical axis of rotation (Fig. 180*c*).

If the axis of the rotor is not orthogonal to the circle described by the globe, as it was in the previous case, but is tangent to it, we nevertheless observe a change of régime at a certain critical velocity, and the eddy, which is at first parallel to the speed V, becomes orthogonal to it and to the axis of the rotor.

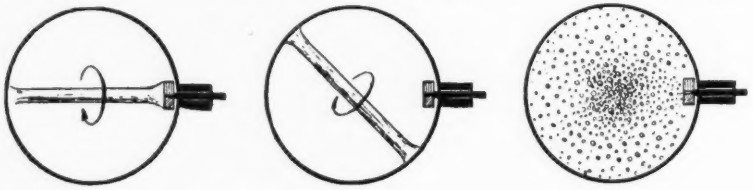


FIG. 181.

When the rotor is placed, not in the middle of the globe but near the wall, as shown on Fig. 181, an increase in the velocity of the whole system tends to turn the vortex out of its original position, as shown on Fig. 181, II, while the motion continues to be regular; but if the angular velocity increases still more and reaches a certain critical value, the motion of water suddenly becomes turbulent—the motion of the air bubbles is completely irregular (Fig. 181, III).

Fig. 182 shows a general view of the apparatus for the study of the phenomena just described.

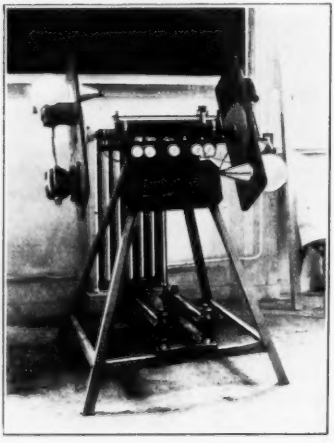


FIG. 182.

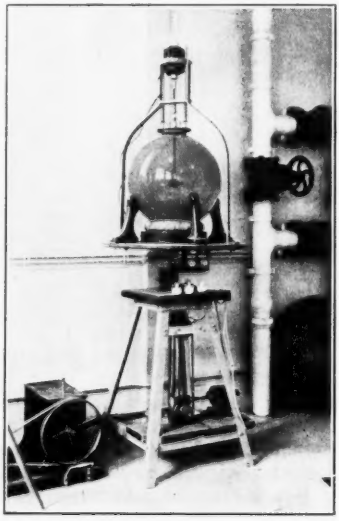


FIG. 183.

The author recently repeated, on a larger scale, the experiment mentioned above in section 13. In this experiment, which the author carried on with a view to giving a hydraulic interpretation of the periodicity of sunspots, the interchange of régimes and consequently of eddy configuration is going on periodically. A view of the new apparatus is shown on Fig. 183.

The diameter of the globe is 60 cm., viz., 1.5 larger than that of the first apparatus shown on Fig. 127. Diagrammatic views of both régimes are shown on Figs. 184 and 185.

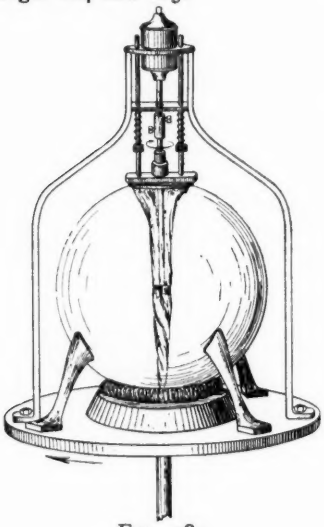


FIG. 184.

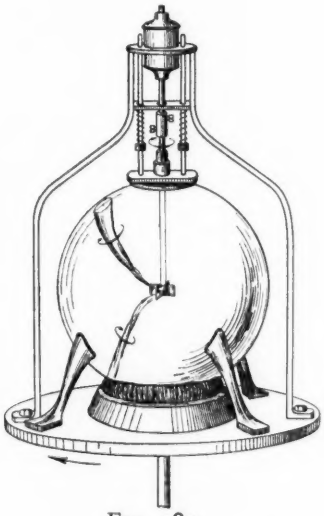


FIG. 185.

By making some simplifying hypotheses and applying dimensional analysis, the author came to the conclusion that in first approximation we can write

$$(t/T)_{\text{sun}} = (t/T)_{\text{model}},$$

where t is the sunspot cycle (period of interchange of régimes) and T the rotation period of the globe. The experimental data are given for comparison in the plate hereunder.

	D cm.	t	T	t/T
1st model ...	40	96 sec.	1.12 sec.	85.7
2nd model ...	60	60 sec.	0.7 sec.	85.5
The sun ...	1.39×10in.	11.5 years	25 days	167.9

The order of magnitude of ratio t/T is the same for the model and the sun. This experiment could be interpreted from the standpoint of J. Wilson's theory, which admits that the sun contains a solid nucleus revolving in a gaseous envelope, the latter still retaining a non-uniform distribution of angular velocities. The friction exerted on water by the globe surface revolving with an angular speed lesser than that of the rotor, could perhaps be compared to the brake effect of radiation to which J. H. Jeans has drawn attention.

25. *Generation of Vortices in a Fluid of Small Viscosity*

In fluids of small viscosity, such as air or water, we often witness the appearance of Rankine's " combined vortices," *i.e.*, fluid motion formed by a nucleus set in rotational motion and surrounded by fluid circulating irrotationally round this nucleus.

These vortices conform fairly well with the limitations of Helmholtz's theory, except to the first of them, which prohibits their generation. In section 16 we saw that two distinct categories of vortex formations are to be considered, free vortices and vortices adjoined or contiguous to moving bodies or to obstacles in a stream.

Generation of free vortices can in most cases be connected with the contraction of cavities in a liquid or local variation of density in a gas. The motion of a fluid in the vicinity of such singularities can be treated as being produced by " sink-eddies " (or " negative source-eddies "—sources-tourbillons). The case of a cavity generating a hollow vortex has already been discussed by Lord Kelvin. The author considers, however, and in this he is not quite in agreement with Lord Kelvin, that when portions a and b of the fluid (Fig. 186) come into contact, a shock ensues and a discontinuity of tangential velocities along the surface of contact can be generated at the same time as the hollow vortex. In a viscous fluid these vortices can have a nave of rotational fluid formed by fluid particles originating from neighbouring boundary layers.

The mechanism of formation of eddies adjoined to solid bodies (section 16) appears at first sight to be rather different.

To explain this mechanism, the author made the following experiment:—

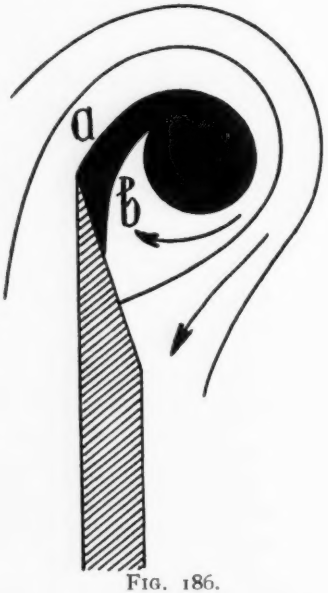


FIG. 186.

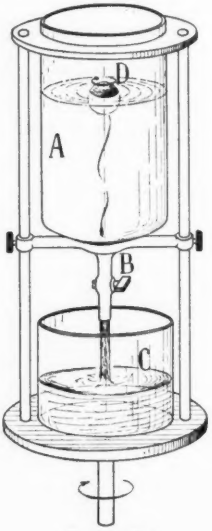


FIG. 187.

The vessel A (Fig. 187) filled with water and supplied with a tube and tap B is placed above vessel C. The whole system can be set in uniform rotation around the vertical axis of the system. At the beginning the tap B is closed. When the régime of velocities $V=\omega r$, where ω is the angular velocity of the system, is established the rotation of vessel A is stopped, whilst the water continues to move by inertia, and tap B is opened and shut again. If the surface of the liquid is free whilst the tap is open a conical cavity generates along the axis. In order to prevent the formation of this cavity it is sufficient to set swimming on the surface of the water a small celluloid sphere D. In both cases, viz., with or without the small celluloid sphere, we see that after closure of tap

B, the régime of velocities has a tendency to submit to the law $vr = \text{const.}$ the small celluloid sphere rotates quicker than before.

Whilst the tap *B* is open, the fluid particles on the free surface describe a trajectory such as represented on Fig. 188.

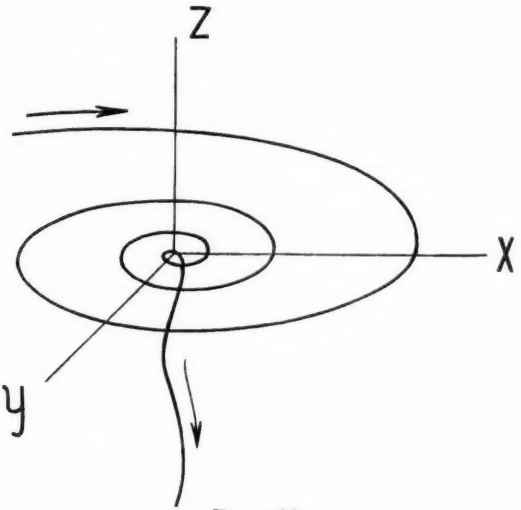


FIG. 188.

Motion in plane *XOY* can be interpreted in first approximation as produced by a sink-eddy placed at the origin. Such singularities will be termed " pseudo sink-eddies."

When tap *B* is closed (Fig. 187), the " sink-eddy " is transformed into an " eddy."

Hence a local depression or suction can determine in a viscous fluid a kind of " noyautage " (concentration) of eddy lines.

The mechanism of this change of velocity can be connected with Kelvin and Rayleigh's researches on the stability of rotating fluids, but the mechanism itself is still far from being elucidated.

The analogy has already been pointed out in section 16, between the motions shown on Fig. 138 and Fig. 142; it is easy to see the connection between those motions and that of Fig. 188. In these three cases the free ends of vortex tubes " debouch " into a domain where pressure is lesser than in that where the pseudo sink-eddy generates. Fluid particles set in rotation arising from neighbouring boundary layers, rush towards sink-eddies and flow along the whirling tubes, keeping up their rotation. The mechanism of " alimentation " of eddies contiguous to aerofoils or to screw propeller blades should be of the same kind.

From the foregoing we may conclude that both classes of eddying motion (free eddies and adjoined or contiguous eddies) may be treated as sink-eddies. These considerations led the author to establish for two dimensional motions the theory of interaction between bodies and source eddies of positive or negative strength (sources-tourbillons) (" C.R. de l'Acad. des Sciences," t. 176, p. 128, 1923; " Bulletin technique du Service technique de l'Aéronautique," No. 17, 1924, p. 45). The most important point of this theory is that the part of pressure p,

$$p = -\tfrac{1}{2}\rho q^2 - \rho \partial\phi/\partial t + f(t),$$

depending upon the square of velocity q, is independent of the motion of source-eddies and can therefore be calculated by considering these punctual singularities as fixed. Hence, it is sufficient to obtain the total pressure of the fluid on the body, to calculate separately the terms which depend upon variation of velocity

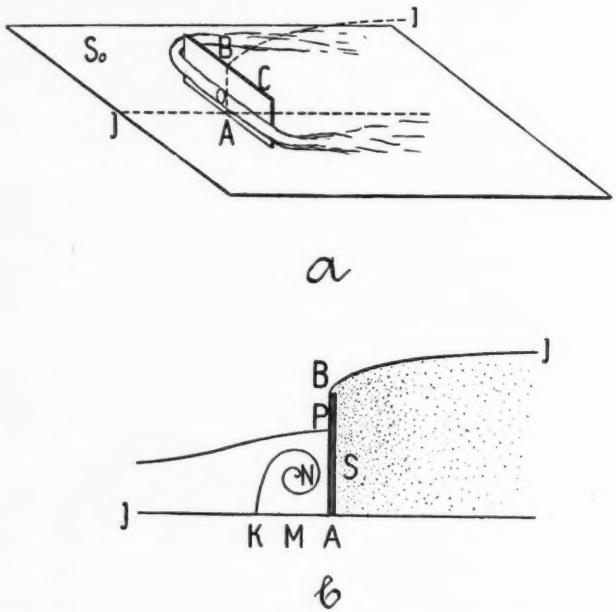


FIG. 189.

potential determined by the motion of source eddies. This theorem is important, as it allows rigorously and in a simple way to calculate the interaction of bodies and eddies, sources or sink-eddies.

The problem of eddies astride bodies led the author to consider the problem of an obstacle with surfaces of slip in the presence of sink-eddies (Fig. 189*a* and *b*).

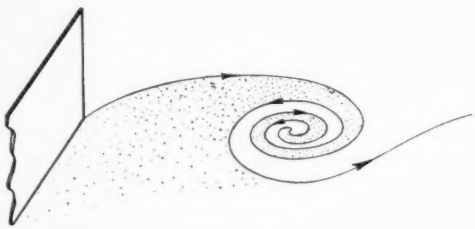


FIG. 190.

The author has also drawn attention to the following singularity. The formation of eddies behind an obstacle is often explained as being due to a rolling over of Helmholtz's slip surfaces breaking into several distinct vortices (Fig. 190).

According to the views of the author, as set forth above, separate " combined vortices " (not simple " rollers ") can generate only as sink-eddies or pseudo sink-eddies, hence such eddies might be generated according to Fig. 191.

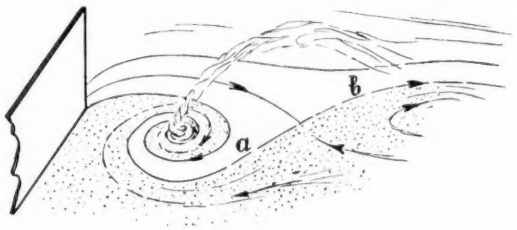


FIG. 191.

The line ab on Fig. 191 is the trace of a surface of discontinuity which separates the fluid in turbulent motion from the fluid which is not yet set in turbulency, and propagates in the latter with a certain relative speed. Normal velocities and the pressure vary in a continuous way, when crossing this surface, but tangential velocities are discontinuous. Careful study of such discontinuities would be important. They can be characterised in certain cases as " shock waves " in a boundary layer. The trace ab of such discontinuity can be seen on the spectre shown on Fig. 86*a*.

The following simple case may give a remote idea of this singularity. Let us consider the motion determined by the velocity potential

$$\phi = (\pm u_1 + u_2)(x^2 - y^2),$$

the signs + and − corresponding respectively to the upper and lower half planes. Since the x axis is a line of discontinuity, the condition, that pressure has the same value at any two adjacent points A and B at opposite sides of the x axis,

$$(\tfrac{1}{2}q^2 + \partial\phi/\partial t)_A = (\tfrac{1}{2}q^2 + \partial\phi/\partial t)_B,$$

is fulfilled, provided

$$du_1/dt = 4u_1u_2.$$

26. *Some New Applications of the Hele Shaw Method*

The Hele Shaw method of coloured filaments between two close parallel plates gives figuration of motions deriving from uniform potentials. It cannot, however, be applied to cyclic motions, for instance to those which play an important part in applied aerodynamics in the theory of aerofoils. The author developed a theory to fill this blank.

In the mathematical proof given by Stokes of the identity of the streamlines in Prof. Hele Shaw's experiments, with those of an irrotational motion of a liquid in two dimensions, the mean velocity u, v, in the stratum and the velocity potential are respectively

$$u = -(h^2/3\mu)(\partial p/\partial x),\quad v = -(h^2/3\mu)(\partial p/\partial y), \quad . \quad . \quad . \quad (1)$$

$$\phi = -(h^2/3\mu)\, p, \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where $2h$ is the distance, supposed to be constant, between the two glasses, p the pressure and μ the viscosity; u, v and p are assumed to be functions of x, y only. It follows that, in order to obtain a cyclic motion, the pressure p, but not the velocities, must be discontinuous on the two sides of a barrier l (Fig. 192) which reduces the region to a simply connected one.

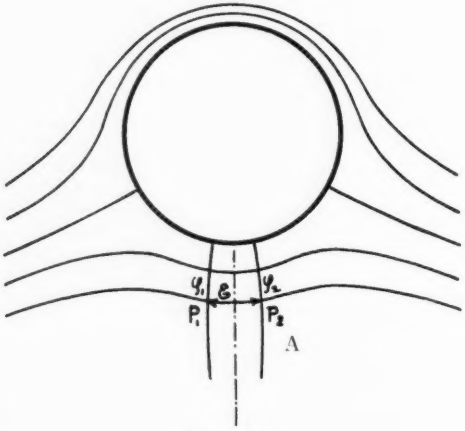
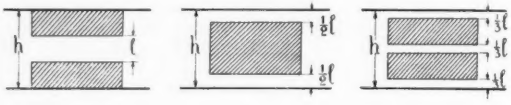


FIG. 192.

It is possible to materialise such a barrier by diminishing the free passage between the two glasses, either directly (Fig. 193*a*), or by introducing one or several laminæ of appropriate shape (Fig. 193*b* and *c*).



a *b* *c*

FIG. 193.

Fig. 194 shows the case when a single lamina is introduced between the glasses.

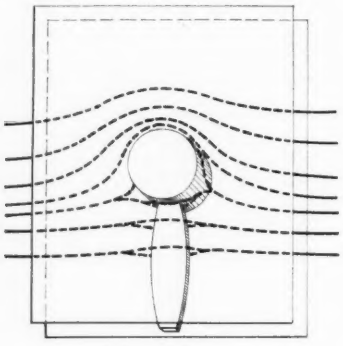


FIG. 194.

When designing by ϵ the breadth of the lamina, in a given point of the barrier, and by u the undisturbed velocity of the fluid in this point (Fig. 192), we have in first approximation

$$(\phi_B - \psi_2)/\tfrac{1}{2}\epsilon = (\phi_1 - \phi_A)/\tfrac{1}{2}\epsilon = u,$$

but

$$\phi_2 - \phi_1 = \kappa,$$

where κ is the cyclic constant, hence

$$-(h^2/3\mu)(p_B - p_A) = \phi_B - \phi_A = \kappa + u\epsilon. \quad . \quad . \quad . \quad (3)$$

Now, referring to the second of formulæ (1) and to the sketch of Fig. 193*b*, and noting that the mean velocity u_1 between the glass and the barrier is connected with the mean velocity u between the two glasses by the relation $u_1 l = uh$, we can write

$$p_B - p_A = -(3\mu/(l/2)^2)\, u_1 \epsilon = -12\mu u\, (h/l^3)\, \epsilon,$$

and, substituting in equation (3), we find the relation

$$\epsilon = \kappa/u\, [4\,(h/l)^3 - 1] \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

If the velocity potential corresponding to a given obstacle is known, the circulation κ and the distribution of velocities u along the barrier are also known, hence equation (4) allows us to calculate the shape of lamina A (Fig. 192) appropriate to the obstacle. If the passage between the two glasses is narrowed, directly (Fig. 193*a*) or by introducing two laminæ (Fig. 193*c*), we find, by repeating the above reasoning, instead of formula (4), formula (5) in the first case and formula (6) in the second case.

$$\epsilon = \kappa/u\, [(h/l)^3 - 1], \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$\epsilon = \kappa/u\, [9\,(h/l)^3 - 1]. \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Comparing formulæ (4), (5) and (6), we see that the breadth ϵ of the lamina in any given point of the barrier can be narrowed the more, and the mean velocities in these points made to differ the less from the theoretical velocities along the barrier, that the clear spaces between the lamina of the barrier become narrower, whilst their total volume remains the same.

The author has also shown that in setting aside the condition of parallelism of glasses, the method of coloured filaments can be extended to the study of symmetrical motion around an axis in one of the sections passing through the latter, and also to the study of the motions of a compressible fluid.

Mme. Popovitch-Schneider, a pupil of the author, submitted the above theory to experimental study. By applying formula (4) she calculated the shape of laminæ for several models and obtained the photograph shown hereunder.

With a view to comparison, photographs obtained with the same models, but without barriers, are also reproduced.

27. *Cavities in Liquids and Accentuated Local Decrease of Density in Gases*

The study of unsteady motions, without neglecting the square of velocities and the shocks, is at present one of the most important problems in mechanics of fluids. It is impossible to develop further the theory of resistance of a liquid or a gas from the standpoint of steady motions only.

As long as the velocity of the fluid surrounding the solid is everywhere small as compared to the velocity of sound waves in the fluid, the effect of the compressibility would not be very great, thus, for instance, air can be treated as an incompressible fluid.

Again, if along a sharp edge of a solid, or inside a vortex, the velocity becomes very great, the formation of a cavity in the liquid corresponds to an accentuated local increase of density of the gas. Consequently, in such a case, the liquid reacts somewhat like a compressible fluid.

It is easier, at least at present, to study mathematically the problem of cavitation in liquids and to interpret afterwards the phenomenon observed in gases, having recourse to the analogy just mentioned.

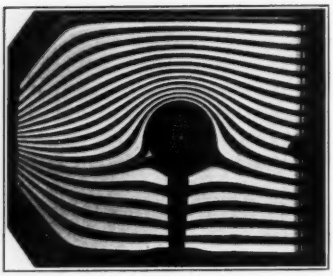


FIG. 195.

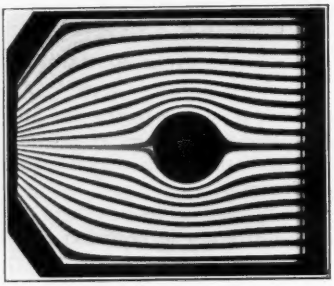


FIG. 196.

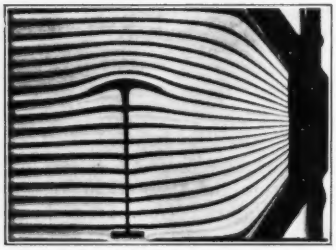


FIG. 197.

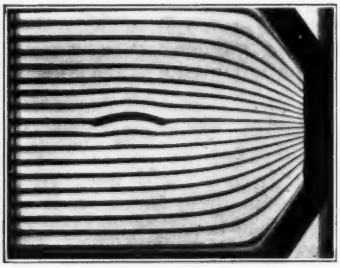


FIG. 198.

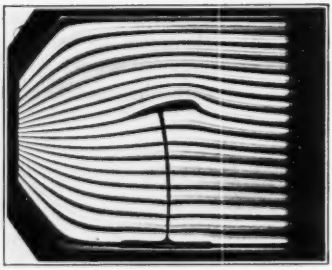


FIG. 199.

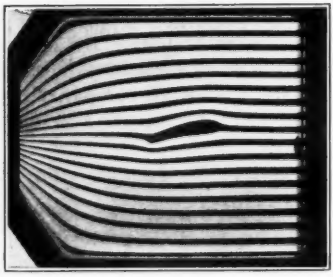


FIG. 200.

These considerations led the author to undertake systematic theoretical researches on the problem of cavitation and to construct an apparatus for the study of the generation of cavities in water which can likewise be used for parallel experiments in air.

Investigations on cavitation led the author to develop a few methods which may present a certain interest, also from the standpoint of pure analysis.

Figs. 201 and 202 show the apparatus for the study of the phenomenon of cavitation. The principle of this apparatus was communicated by the author to the Air Congress in London in 1923.

The closed vessel A (Fig. 201) provided with end a is completely filled with water. The body b, a disc on the figure, initially fixed in the middle of the vessel,

is suddenly set in motion by a falling weight *c*. The volume and speed of the water flowing out through the aperture *a* enables us to record the change of volume of cavities as a function of time.

The volume of cavities is increased when external pressure is diminished, for instance, by a vacuum in the globe *e* which can be fixed on end *a*.

In repeating this experiment when vessel *A* is filled with air, the tube *d* (see Fig. 201) serves as prolongation of the vessel's end *a*. When disc *b* is

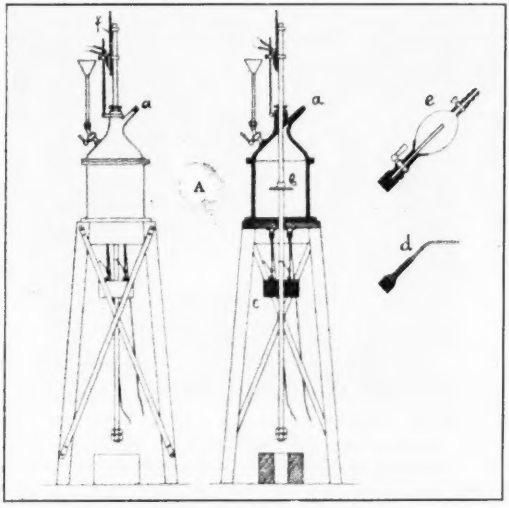


FIG. 201.

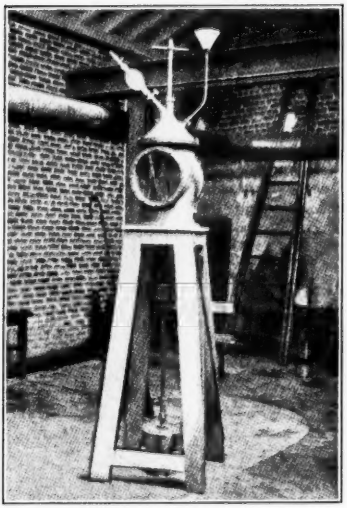


FIG. 202.

set in motion by the falling weight, only a very small quantity of the water introduced previously in tube d is projected and its volume, in accordance with an approximate theory developed by the author, is nearly 700 times less than the volume of water ejected when the vessel was filled with water.

In order to photograph the cavities, the apparatus is fitted with two glasses. Photographs were obtained by utilising the lighting apparatus with neon lamp (Stroborama) of L. and A. Séguin and with the collaboration of the latter.

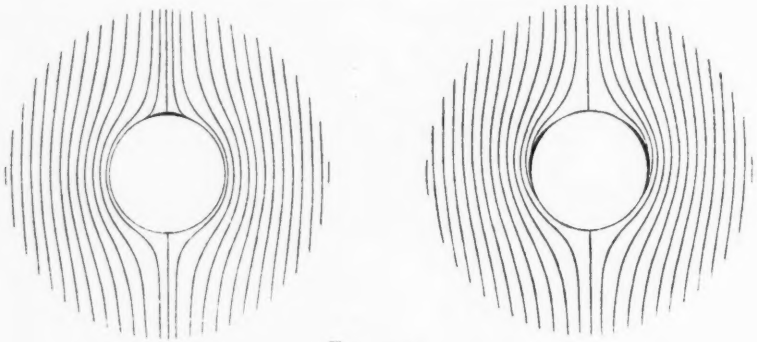


FIG. 203.

The author demonstrated that if a sphere (or a circular cylinder) is suddenly set in motion in a liquid initially at rest, the fluid will separate itself from the surface on an area surrounding the pole and if the sphere is moving with a constant speed, and external pressure diminishes suddenly, the fluid will separate itself from the sphere on an annular surface on the equator.

Streamlines of relative initial motion around a circular cylinder corresponding to both cases just mentioned and the generated cavities shown on Fig. 203 have been calculated by the author's pupil, B. G. Demtchenko.

FIG. 204.

FIG. 205.

In experiments described hereunder, the body and its sustaining axis were set in motion by the fall of a weight of 30 kilos. from a height of 80 cm. The initial velocity was 4 metres per second, and the body afterwards displaced itself for a distance of 10 cm. at an approximately constant speed.

FIG. 206.

Figs. 204, 205 and 206 show cavities generated by sudden setting in motion of a sphere in water, external pressure being 76 cm. of mercury.

On Figs. 207 and 208 we see cavities generated by sudden setting in motion of a sphere in water, external pressure being brought down to 6 cm. of mercury.

FIG. 207.

FIG. 208.

On Figs. 204 and 207 the distance covered by the sphere after the percussion was approximately 1 cm. On the other figures this distance increases progressively.

The above figures show that the cavities begin to grow at the top of the sphere; they tend afterwards to detach themselves from the sphere and contract abruptly, leaving only a small residue of air bubbles, as seen on Fig. 206. When external pressure decreases, the volume of the cavity must be larger. This can be observed on Figs. 207 and 208. On Fig. 208 we observe that, whilst the cavity determined by the initial acceleration of the sphere begins to contract,

FIG. 209.

FIG. 210.

FIG. 211.

an annular cavity analogous to that traced on Fig. 203*b* arises on the equator of the sphere.

When replacing the sphere by a body with sharp edges, say a disc, the curvature of streamlines being very great in the vicinity of the edges, the centrifugal force tends to detach the fluid from the solid. In these conditions, as explained in section 25, cavities are seen to arise closely following the edges and detaching themselves therefrom as hollow vortices.

Fig. 209 shows generation of an annular cavity along the edge of a biassed disc.

On Fig. 210 we can follow the transformation of an annular cavity into a hollow vortex under external pressure measuring 76 cm. of mercury, and on Fig. 211 we see the same processes, but under pressure of 6 cm. of mercury.

In bi-dimensional motions two hollow vortex tubes parallel to the biassed edges of the plane will be generated.

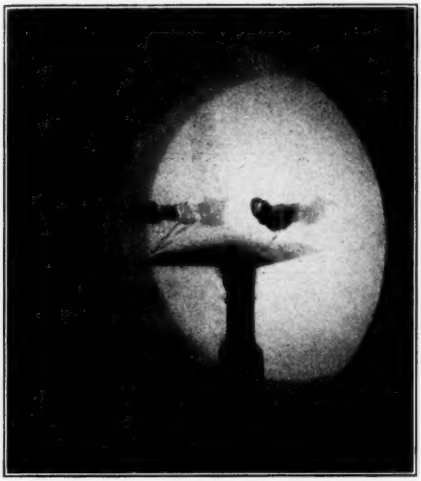


FIG. 212.

FIG. 213.

FIG. 214.

Fig. 212 shows the generation of hollow vortex tubes parallel to the edges of the plate and Fig. 213 the formation of hollow vortex tubes along the edges of an oblique plate.

As previously indicated, motions determined in the air around accelerated bodies, must be similar to those obtained in water under like conditions.

In order to visualise the motion of air, the surface of the bodies was previously sprinkled with lycopodium powder.

In Fig. 214 we see a sphere sprinkled with lycopodium powder suddenly set in motion in air initially at rest.

FIG. 215.

FIG. 216.

Fig. 215 corresponds to a sudden setting into motion of a rectangular biassed plate sprinkled with lycopodium powder, and Fig. 216 to that of an oblique rectangular plate in same conditions.

When comparing Figs. 215 and 216 with Figs. 212 and 213, we see that motion in water and in air is truly near akin.

28. *Impact with a Liquid Surface. Explosions under Water. Air Bubbles. Vortices Arising on the Opening of a Parachute*

In the figures given above, the bodies suddenly set in motion were completely immersed in the fluid. When a disc or a rectangular plate strikes against the free surface of a liquid and afterwards sinks, other phenomena can be observed. The theory can be related, in first approximation, to that of free surfaces or finite slip in steady motion.

Interesting experiments on the impact of a sphere with a liquid surface were made by A. M. Worthington and R. S. Cole, who studied this problem by the aid of instantaneous photography at the end of the 19th century.

Three views of a disc sinking in water are shown on Figs. 217, 218 and 219.

Figs. 220 and 221 give instances of such motion in two dimensions.

Fig. 220 shows a rectangular plate sinking in water at right angles, and on Fig. 221 we see the sinking in water of an oblique plate.

Theoretical discussion of the problem of the stability of cavitation led the author to undertake experimental researches upon explosions under water.

A few grammes of gunpowder were introduced into a small glass tube placed under water in the middle of an aquarium as shown on Fig. 222.

The elevation of the free surface lights the spark which records the explosion on the sensitive plate. Fig. 223 was thus obtained. The cavity containing the gases produced by the explosion appears on the figure as a dark spot.

FIG. 217.

FIG. 218.

FIG. 219.

Another experiment will be mentioned which, although not directly related to the stability of cavities, is nevertheless connected with the question of explosions under water and has given rather curious results.

A glass cylinder filled with water, with a charge of gunpowder introduced in it, is shown in Fig. 224.

FIG. 220.

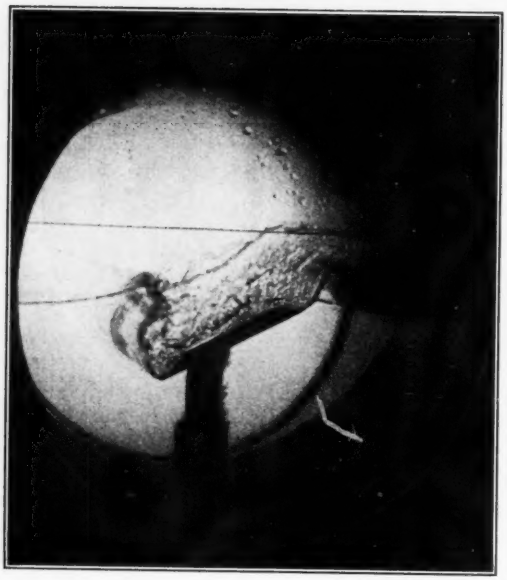


FIG. 221.

Fig. 225 gives a view of the curious deformation of the glass cylinder previous to bursting.

A few fragments of glass produced by the explosion of a sphere and a cylinder filled with water are shown on Fig. 226.

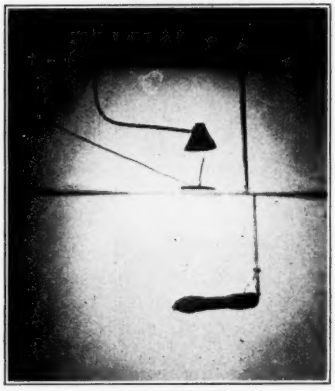


FIG. 222.

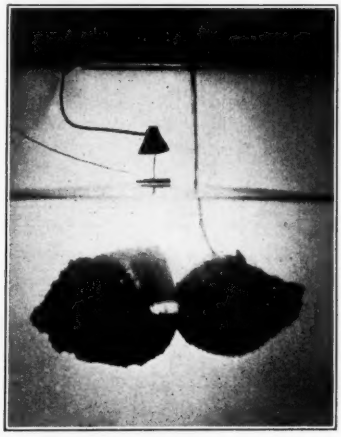


FIG. 223.

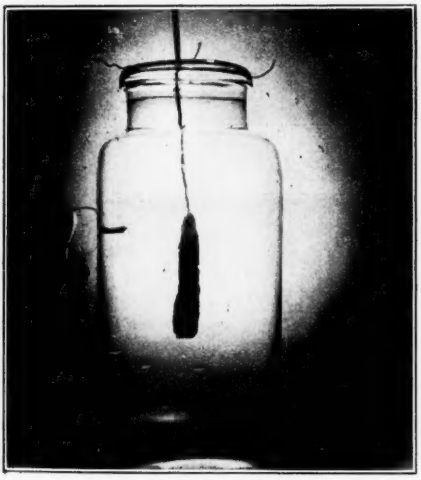


FIG. 224.

FIG. 225.

The explanation of the peculiar deformation of the glass cylinder shown on Fig. 225 must be sought in the glass fragments splits, the edges of which were stretched asunder by the explosion.

The problem of air bubbles rising to the surface also comes within the province of the cavitation problem. Theoretical considerations show that an initial

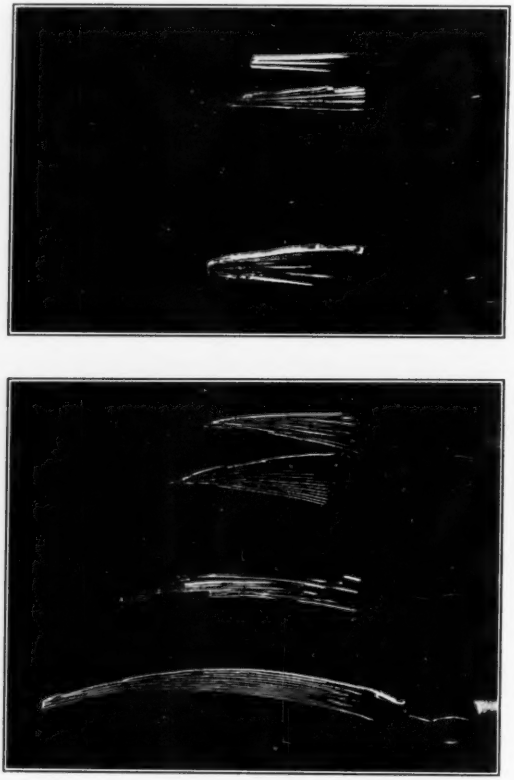


FIG. 226.

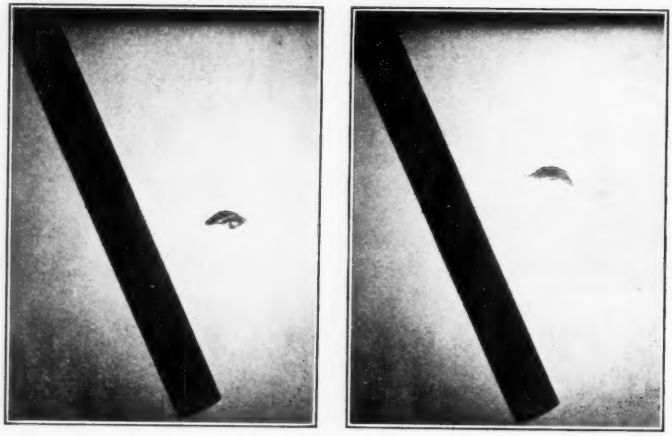


FIG. 227.

spherical cavity has a tendency to flatten, becoming concave from below, like a mushroom pileus.

In Fig. 227 we see air bubbles in three dimensions and in Fig. 228 air bubbles in two dimensions, between close parallel plates.

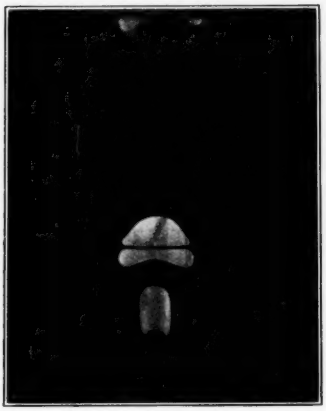


FIG. 228.

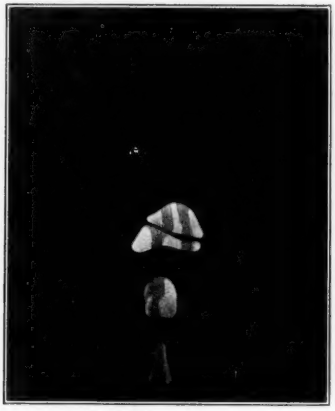


FIG. 228a.

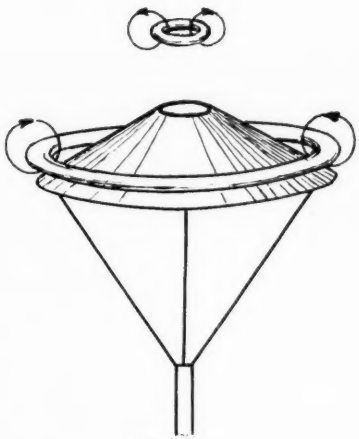


FIG. 229.

A vortex system generated by an opening parachute must have the configuration shown on Fig. 229.

To show that this is truly so, the author placed in the apparatus for cavitations, filled with water, the small parachute model shown on Fig. 230.

Both vortex rings of Fig. 229 can be seen on photograph 231.

FIG. 230.

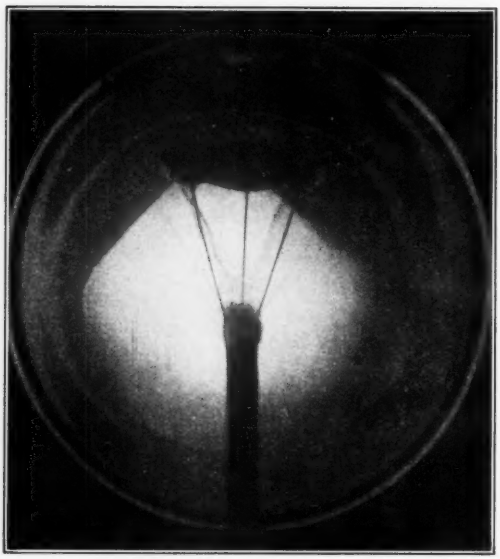


FIG. 231.

29. *On Some Recently-Constructed Apparata and Researches Pursued*

In this section some of the apparata constructed since 1929 will be mentioned. Most of the photographs represent these apparata such as they figured at the XIIIth " Salon de l'Aéronautique " in Paris, in 1932.

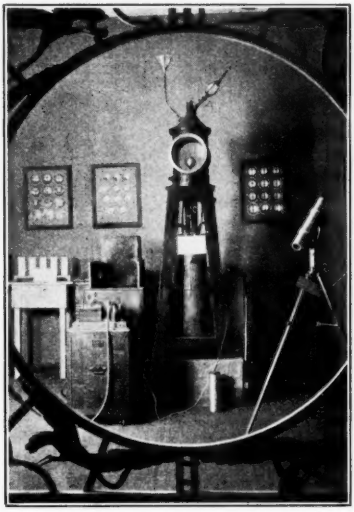


FIG. 232.

Fig. 232 represents the cavitation apparata mentioned in the preceding section, but fitted with a special pneumatic contrivance for lifting and thrusting the weight which suddenly sets in motion the bodies placed in the apparatus.

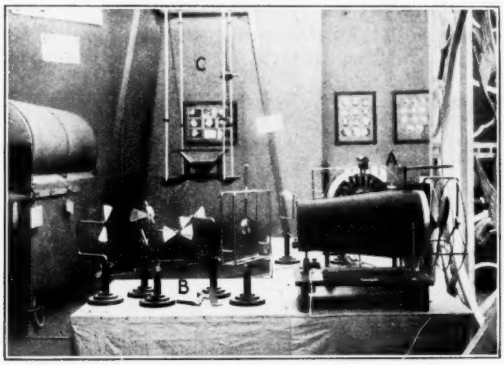


FIG. 233.

On Fig. 233 we see a small wind tunnel (*A*) for demonstrations and a set of apparata (*B*) for reproducing the experiments mentioned in preceding chapters. This figure also shows an apparatus (*C*) for studying the reaction of gaseous

jets and the influence of acceleration in the relative motion of fluids; it also served as a ballistic pendulum and as an aerodynamic and airscrew balance.

This apparatus consists of an oscillating table, which remains parallel to itself; the motion of this table is consequently only a motion of translation. On the figure we see a triangular vessel containing a liquid, which is placed on the table. For this kind of vessel Kirchhoff has studied the free two-dimensional

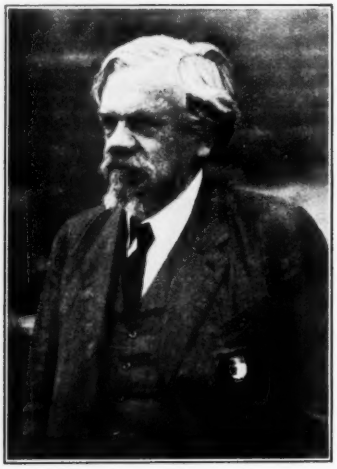


FIG. 234.

oscillations of water. As can easily be demonstrated, when the table oscillates, the surface of the liquid must remain nearly plane and orthogonal to the rods which sustain the table; hence the oscillations of water in the recipient have the same period as the table. When the latter is stopped the liquid continues to oscillate, but with its own period.

With a view to record the deformation and vibration of bodies, the author suggested the utilisation of the variation of electric resistance of thin layers, in

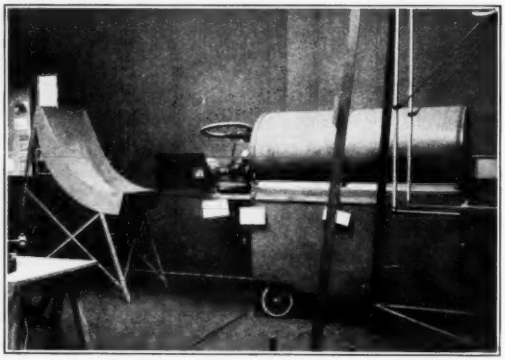


FIG. 235

function of deformations of their support. The author's pupil, Mr. A. Guerbilsky, constructed a special apparatus based upon this principle.

In the course of the last few years, the author gave much attention to the study of the resistance of compressible fluids at high speeds and drew attention in France to a remarkable, although well-nigh forgotten theoretical paper by

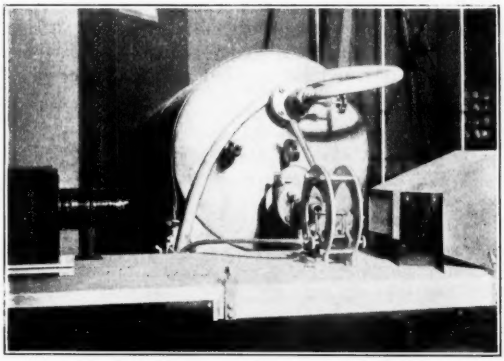


FIG. 236.

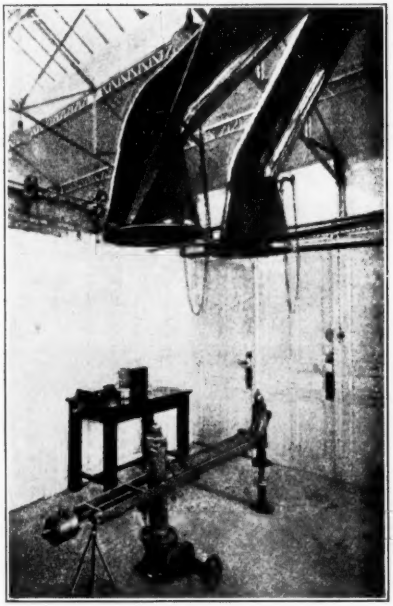


FIG. 237.

Prof. Chaplyguin, published in Moscow in 1902. Dr. B. Demtchenko felt interested in this theory and succeeded in considerably enlarging it. Fig. 234 shows the portrait of S. A. Chaplyguin.

On Figs. 235 and 236 two aspects are shown of a small supersonic free jet tunnel.

On Figs. 237 and 238 another apparatus is shown for studying the laws of air resistance at high speeds. In apparatus *a* a piezo-electric dynamometer of new type is used.

Usual piezo-electric dynamometers have the disadvantage that they require to be very carefully isolated when it is necessary to measure constant or slowly varying pressures. To remedy this difficulty, Mr. A. Guerbilsky, upon the author's suggestion, constructed a dynamometer in which a piezo-electrical crystal is set into vibrations, whilst applied pressure modifies the conditions of these vibrations.

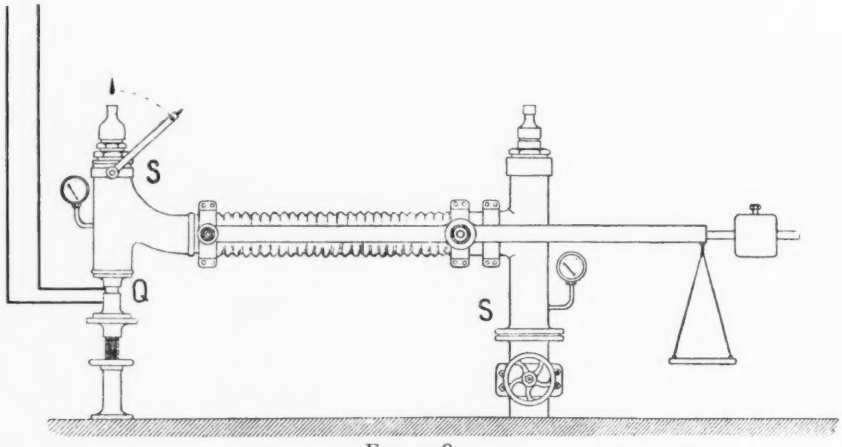


FIG. 238.

To put in evidence the special peculiarities appearing at speeds exceeding that of sound waves and more especially the character of streamlines crossing the shock waves, the author applied the method of aerodynamic spectres set forth in section 6. He wished to ascertain whether in a shock wave streamlines have always the form which is generally admitted as indicated on Fig. 157, or if, on

FIG. 239.

the contrary, a contraction such as indicated on Fig. 158 can arise. On several of the spectres obtained such contractions seem to appear.

The author's pupils, V. Volkovisky and A. Katlama, by applying the method of aerodynamic spectres at high speed, obtained interesting results.

30. *The Hydraulic Analogy of the Motion of a Compressible Fluid as an Aid to Aeronautical Researches*

The analogy between undulating motion on the surface of water and those which arise in air, as well as the analogy between the phenomenon of the bore and that of the shock wave, are well known and have given rise to numerous researches. Prof. E. Jouguet gave the name of " hydraulic gas " to a gas in which the power γ of the characteristic equation $p/p_0=(\rho/\rho_0)^\gamma$ would equal 2.

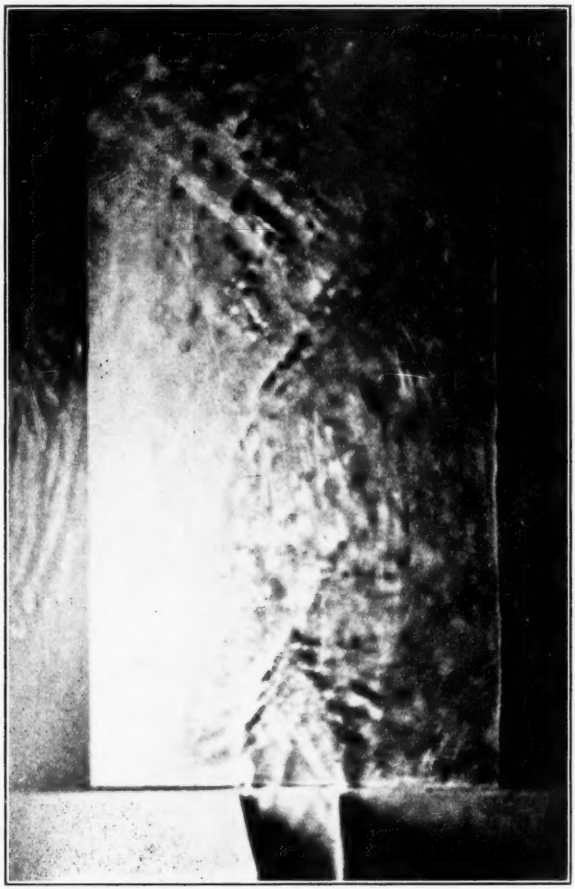


FIG. 240.

The author generalised the theory of hydraulic analogy to the motion of a gas in two dimensions, with a view to developing a method of experimental research based on such analogy and constructed a model of an apparatus specially designed for such a study.

On Fig. 239 we see this apparatus indicated by *A* as it appeared at the " Salon de l'Aéronautique " in 1932. The phenomenon which visitors to the Salon could observe was that of hydraulic analogy of the flow in two dimensions of a gas under pressure by an ajutage. When standing at *B* and observing in glass *C* the surface of the water reflecting the light of lamp, one clearly sees a system of waves forming lozenges similar to those of Emden, Mach, Prandtl and Stanton.

Fig. 240 and Fig. 241 show two photographs obtained with this apparatus. The latter was obtained by previously sprinkling the surface of the water with lycopodium powder.

FIG. 241.

A diagram view of this experiment is shown in Fig. 242.

The author demonstrated that there exists a close bond between the forces and the moments exerted upon a cylinder of height l placed in a two-dimensional aerodynamic tunnel (Fig. 243*a*) and upon a cylinder of same section placed in a tank of hydraulic analogy of depth $h=l$ (Fig. 243*b*).

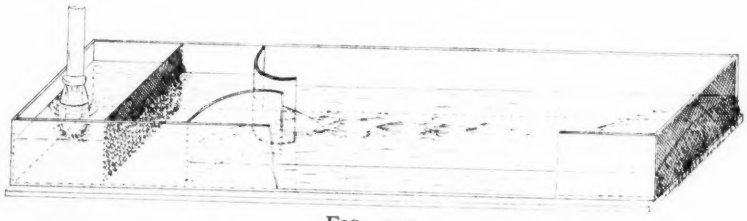
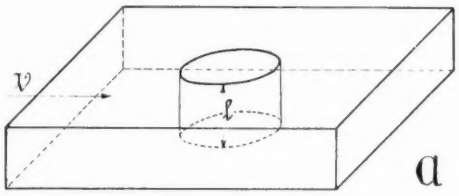


FIG. 242.

It follows from this theory that a tank devoted to such researches (not deep, but wide) could be very useful for investigations on resistance of compressible fluids.



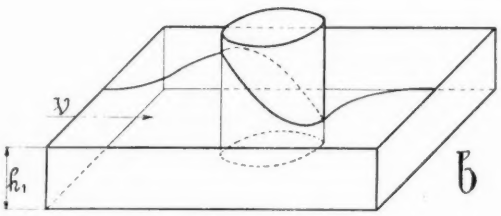


FIG. 243.

Experimental study of non-permanent motions, for instance of motions determined by a flapping wing, would probably be difficult to realise in air at supersonic speeds; on the contrary, in the " tank of hydraulic analogy," such study would not present any difficulty. It is still necessary, to obtain a quantitative coincidence, to calculate the correction for the passage from the " hydraulic gas " to air. In first approximation, this question has already been examined by the author.

Let us take an example of the application of the above-mentioned analogy. As is known, the substantive properties of aerofoils decrease at high speed. The author thought this could be remedied to a certain extent by joining to the aerofoils planes parallel to the motion, in order to determine a reflection of the upper wave of over-pressure downwards, and of the lower wave of depression upwards. The interference of waves could also be utilised to decrease the resistance of bodies.

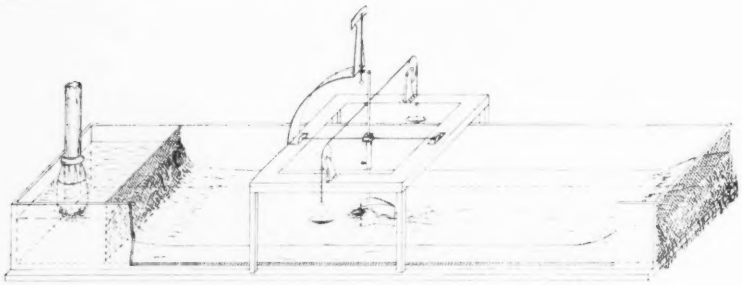


FIG. 244.

In order to submit this reasoning of experimental trial, the author studied in a small preliminary tank of hydraulic analogy the thick blade R.A.F. of L. G. Briggs and H. L. Dryden. The arrangement used in this preliminary investigation is shown diagrammatically on Fig. 244. The reflecting plane was placed at a certain distance above the leading edge of the aerofoil, as shown on Fig. 245.

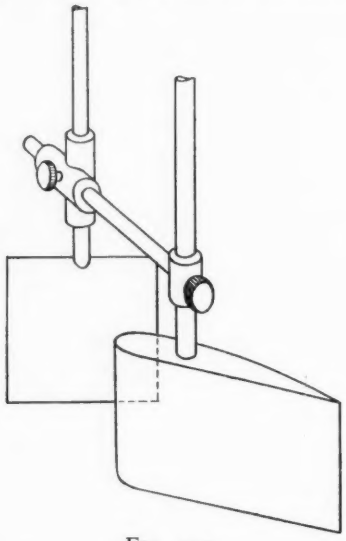


FIG. 245.

The respective values of the non-dimensional lift and drag coefficients K_y, K_x, and those of the ratio of lift to drag K_y/K_x are given below. The angle of incidence was 15° and the ratio of the stream velocity V to the wave velocity C, far from the obstacle, was 1.75.

	K_y	K_x	K_y/K_x
Aerofoil without reflector ...	0.213	0.115	1.85
Aerofoil with reflector ...	0.262	0.098	2.61

This preliminary experiment confirms the theoretical forecast and the principle of reflecting planes may find useful application.

Conclusion

We find in Professor Bairstow's " Applied Aerodynamics " the following lines concerning the Koutchino Institute :—

" The other European laboratory of note was at Koutchino, near Moscow, with D. Riabouchinsky as director. This laboratory appears to have been a private establishment, and played a very useful part in the development of some of the fundamental theories of fluid motion. The practical demand on the time of the experimenters appears to have been less severe than in the more Western countries."

A certain feeling of disapprobation may seem to be implied in the last sentence, but I cannot deny the correctness of the assertion. I have, in fact, always considered that the purpose of Fluid Mechanics Laboratories should not be confined to collecting data as demanded by current practice and to methodical improvement of details, but that sight should not be lost of the search for general laws and principles and new ways. The latter investigations do not contribute less than the former to the development of technics.

I cannot be a judge to decide whether my researches have furnished new instances to uphold the above-mentioned thesis. From the numerous textbooks on Fluid Mechanics, and special articles in Encyclopediæ, published in various countries within the last few years, this would not appear to be the case; my works are seldom, if ever, quoted.

However, two years ago, the well-known hydraulic engineer, Dr. John R. Freeman, wrote me that he was particularly interested in fully establishing the credit among American readers that I originated many of the tests that have since appeared in various publications on hydrodynamics and aerodynamics without being credited back to my initiative. This intention of the eminent American engineer was not fated to materialise in his lifetime.

The Royal Aeronautical Society now affords me the possibility, which I highly appreciate, of giving in the English language an account of my researches and ideas.

List of Papers by D. P. Riabouchinsky

Abbreviations Adopted

Bul. Koutchino—Bulletin de l'Institut Aérodynamique de Koutchino.
C.R. Acad. Sc.—Comtes Rendus de l'Académie des Sciences de Paris.

First Period (1904-1909)

1. Notice Descriptive de l'Institut Aérodynamique de Koutchino. Moscow, 1905.
2. Etude du Courant Aérien Artificiel dans un Tube destiné à des Expériences sur la Résistance de l'Air. Bul. Koutchino, I, 1906.
3. Recherches sur l'Helice Aérienne dans un Courant Aérien dirigé perpendiculairement a l'Axe de l'Helice. Bul. Koutchino, 1, 1906.
4. Recherches sur la Rotation de Plaques Symetriques dans un Courant Aérien et sur la Détermination de la Pression qu'elle supporte. Bul. Koutchino, 1, 1906.
5. Note sur l'Autorotation de Plaques Symetriques dans un Courant Aérien et un Courant d'eau. Bolletino della Societa Aeronautica Italiana (February, 1908).
6. Appareil pour l'Etude du Frottement de l'Air contre un Plan. Bolletino della Societa Aeronautica Italiana (July, 1908).
7. Recherches sur les Helices Aériennes. Bul. Koutchino, II, January 1909.
8. Du Choc d'un Courant Illimité contre une Plaque. Bul. Koutchino, T.III, 1909.
9. Note sur les Tubes à Ventilation destinés a des Expériences sur la Résistance de l'Air. Bul. Koutchino, III, 1909.
10. Recherches sur la Pression que supportent des Plaques Rectangulaires en Rotation dans un Courant Aérien. Bul. Koutchino, III, 1909.
11. Spectres Aerodynamiques. Bul. Koutchino, III, 1909.

Second Period (1910-1918)

12. Note sur une Expérience de M. Rateau. L'Aérophile, Paris, 1r avril, 1910.
13. Note sur les Helices Aériennes. La Technique Aeronautique, Paris, 1r septembre, 1910.
14. Etude sur le Tunnel de M. Eiffel. La Technique Aéronautique, Paris, 15 décembre, 1910.
15. Recherches sur les Mouvements Pendulaires. L'Aérophile, Paris, 1r janvier, 1911.
16. Methode des Variables de Dimension Zéro. L'Aérophile, Paris, 1r septembre, 1911.
17. Recherches Théoriques sur les Hélices. Moscow, July, 1912.
18. Etude sur le Tarage des Tubes de Pitot. Bul. Koutchino, IV, 1912.
19. De la Pression d'un Courant Aérien sur des Plaques Carrées de Petite Dimension. Bul. Koutchino, IV, 1912.
20. Considérations Générales sur la Méthode du Courant d'Air Artificiel. Bul. Koutchino, IV, 1912.
21. Sur la Question du Mouvement d'un Fluide Incompressible entourant un Corps Solide en Mouvement. Bul. Koutchino, IV, 1912.
22. Essai sur les Hélices. Bul. Koutchino, IV, 1912.
23. Laboratoire Hydrodynamique. Bul. Koutchino, IV, 1912.
24. Expérience d'Hydrodynamique. Bolletino de Aero-Club di Roma, March, 1914.
25. De la Rotation des Disques dans les Fluides Visqueux. Bul. Koutchino, V, 1914.
26. De la Répartition des Vitesses dans un Tourbillon Forcé. Bul. Koutchino, V, 1914.
27. Etude Experimentale sur le Frottement de l'Air. Bul. Koutchino, V, 1914.
28. Sur la Résistance des Spheres et des Ellipsoides dans les Tunnels. Bul. Koutchino, V, 1914.
29. Sur les Tourbillons Adjoints. Bul. Koutchino, V, 1914.
30. Sur les Phénomènes Hydrodynamiques Intermittents. Bul. Koutchino, V, 1914.
31. Essai d'un Calcul des Valeurs Absolues. Bul. Koutchino, V, 1914.
32. On the Principle of Similitude. Nature, Vol. XCV, p. 105, London, 1915.
33. On the Reaction of a Gaseous Jet (in Russian). Moscow, 1916.
34. On Air Resistance at High Speeds (in Russian). Moscow, 1916.

Third Period (1919-1934)

35. Calcul des Valeurs Absolues. Copenhague, 1919.
36. On Steady Fluid Motions with Free Surfaces. Proc. London Mathem. Societ, Ser. 2, vol. 19, Part 3, 1920.
37. Cinematique des Mouvements Discontinus dans les Fluides. Bul. Koutchino, VI, 1920.

38. Sur la Résistance de l'Air aux Grandes Vitesses. Bul. Koutchino, VI, 1920.
39. Sur l'Autorotation des Projectiles. Bul. Koutchino, VI, 1920.
40. De l'Influence du Vent dans le Repérage par le Son. Bul. Koutchino, VI, 1920.
41. Appareils de Calcul pour Stations de Repérage par le Son. Bul. Koutchino, VI, 1920.
42. Théorie des Fusées. Bul. Koutchino, VI, 1920.
43. Considérations Générales sur les Hélices. Bul. Koutchino, VI, 1920.
44. Sur les Séries de Fourrier. Bul. Koutchino, VI, 1920.
45. Sur la Résistance des Fluides. Comptes-Rendus du Congrès International des Mathématiciens à Strasbourg, 1920.
46. Sur le Calcul des Valeurs Absolues. Comptes-Rendus du Congrès International des Mathématiciens, Strasbourg, 1920.
47. Mouvement Initial d'un Liquide en Contact avec un Obstacle a Arêtes Vives. C.R. Acad. Sc., 28 février, 1920.
48. Mouvement Cyclique d'un Liquide autour d'un Solide qui se meut parallèlement à une Paroi Rectiligne. C.R. Acad. Sc., 4 juillet, 1921.
49. Equations Generales du Mouvement de Corps Solides dans un Fluide Parfait Incompressible. C.R. Acad. Sc., 7 novembre, 1921.
50. Equations du Mouvement d'un Fluide rapportées a des Axes Mobiles. C.R. Acad. Sc., 24 octobre, 1921.
51. Sur la Résistance des Fluides Visqueux. C.R. Acad. Sc., 21 novembre, 1921.
52. Quelques Considérations sur la Forme du Solide et l'Energie Cinétique du Fluide qui l'Entoure. C.R. Acad. Sc., 23 janvier, 1922.
53. Sur quelques cas de Mouvements Plans des Fluides autour de Solides avec Tourbillons. C.R. Acad. Sc., 6 mai, 1932.
54. Sur les Equations du Mouvement a deux Dimensions de Solides dans un Liquide avec Tourbillons. C.R. Acad. Sc., 11 septembre, 1922.
55. Recherches d'Hydrodynamique. Thèse de doctorat, Paris, 1922.
56. Sur les Equations Générales du Mouvement de Corps Solides dans un Liquide Incompressible. Thèse de doctorat, Paris, 1922.
57. Sur les Mouvements Plans des Fluides autour de Solides avec Tourbillons. C.R. du Congrès de l'Association Française pour l'Avancement des Sciences Montpellier, 1922.
58. Sur la Résistance des Fluides. Proceedings of the Air Congress, London, 1923.
59. Aperçu sur Quelques Recherches de Balistique. Mémorial de l'Artillerie Française, 1923.
60. Sur le Paradoxe de d'Alembert. C.R. Acad. Sc., 23 avril, 1923.
61. Sur les Cavitations et la Resistance des Fluides. C.R. Acad. Sc., 10 décembre, 1923.
62. Sur Quelques Propriétés Générales des Mouvements Plans d'un Liquide. C.R. Acad. Sc., 3 novembre, 1924.
63. Quelques Considérations sur les Mouvements Plans Rorationnels d'un Liquide. C.R. Acad. Sc., 24 novembre, 1924.
64. Discussion de quelques Expériences dans un Fluide Animé de Rotation. Proceedings of the First International Congress of Applied Mechanics, Delft, 1924.
65. Aperçus Théoriques sur la Mécanique des Fluides. (Fascicule I.) Bulletin du Service Technique de l'Aéronautique, avril, 1924.
66. Sur Quelques cas de Mouvements Irrotationnels a Trois Dimensions. C.R. Acad. Sc., 7 décembre, 1924.
67. Sur la Résistance des Fluides et la Réaction d'un Jet. C.R. du III-me Congrès International de la Navigation Aérienne, Bruxelles, 1925.
68. On Some Cases of Two Dimensional Fluid Motions. Proceedings of the London Mathematical Society, Ser. 2, vol. 25, Part 3, 1926.
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THE THURSTON ROTOR COWL FOR AIR-COOLED ENGINES. A NEW METHOD FOR COOLING AND REDUCING HEAD RESISTANCE

BY

A. P. THURSTON, F.R.Ae.S., D.Sc.

One of the main problems in connection with the development of air-cooled engines appears to consist in securing adequate cooling without increasing the head resistance above that of corresponding water-cooled engines.

This problem particularly applies to large air-cooled engines which are limited in size by cooling difficulties. Air-cooled engines for windmill planes and helicopters for alternate slow and fast flying present a further problem, because such aircraft engines will be required to develop maximum horse-power when the speed of translation is lowest.

The airflow over the nose of a bulky body, such as that of an aeroplane, diverges radially in every direction from its axis. Such radial flow tends to overshoot laterally, at its core, the periphery of the engine or other obstruction and so depart from the contour thereof, with the result that a considerable turbulence is set up. Such turbulence has also the undesirable effect of causing a reversal of the pressure gradients, and a corresponding reversed or forward flow of air, in the boundary layer behind the engine, thereby creating a " dead " area or areas and so considerably reducing the cooling effect of the general air flow and increasing the turbulence.

The Townend Ring and other engine cowls have reduced the head resistance and increased the cooling effect (or at least have not seriously interfered with the cooling effect) by acting upon this divergent radial flow.

A new method of solving the problem is provided by moving approximately peripherally of the radial airflow over the front of the engine, to form a flow-regulating " surface or ring of revolution," one or more elemental aerofoils or riders, each of which is of aerofoil shape in cross sections in planes perpendicular to its path, and each of which is preferably of arcuate shape in end view in any plane perpendicular to the axis of rotation.

A simple explanation of the principle by analogy with the Townend Ring is as follows:—

A section of the Townend Ring consists of an aerofoil having a considerable lift coefficient with a forward component which acts on the radial airflow, forcing the air into contact with the engine and obtaining a forward component thereby.

If a section of such a ring is moved in a circular path concentric with the axis of the ring, the only force required to move it will be that necessary to overcome air and other friction. But if such a section, or the front portion of such a section is shaped as an aerofoil in relation to its circular path and is inclined or given " an angle of incidence " relative to the said circular path, then the section will autorotate in one direction and require power to drive it in the opposite direction. Certain sections have been found which will autorotate without being given an angle of incidence. The friction of the inclined section is so small in comparison with the driving force that, if free to do so, it will rotate about its axis with great speed, giving a powerful forward component like a solid

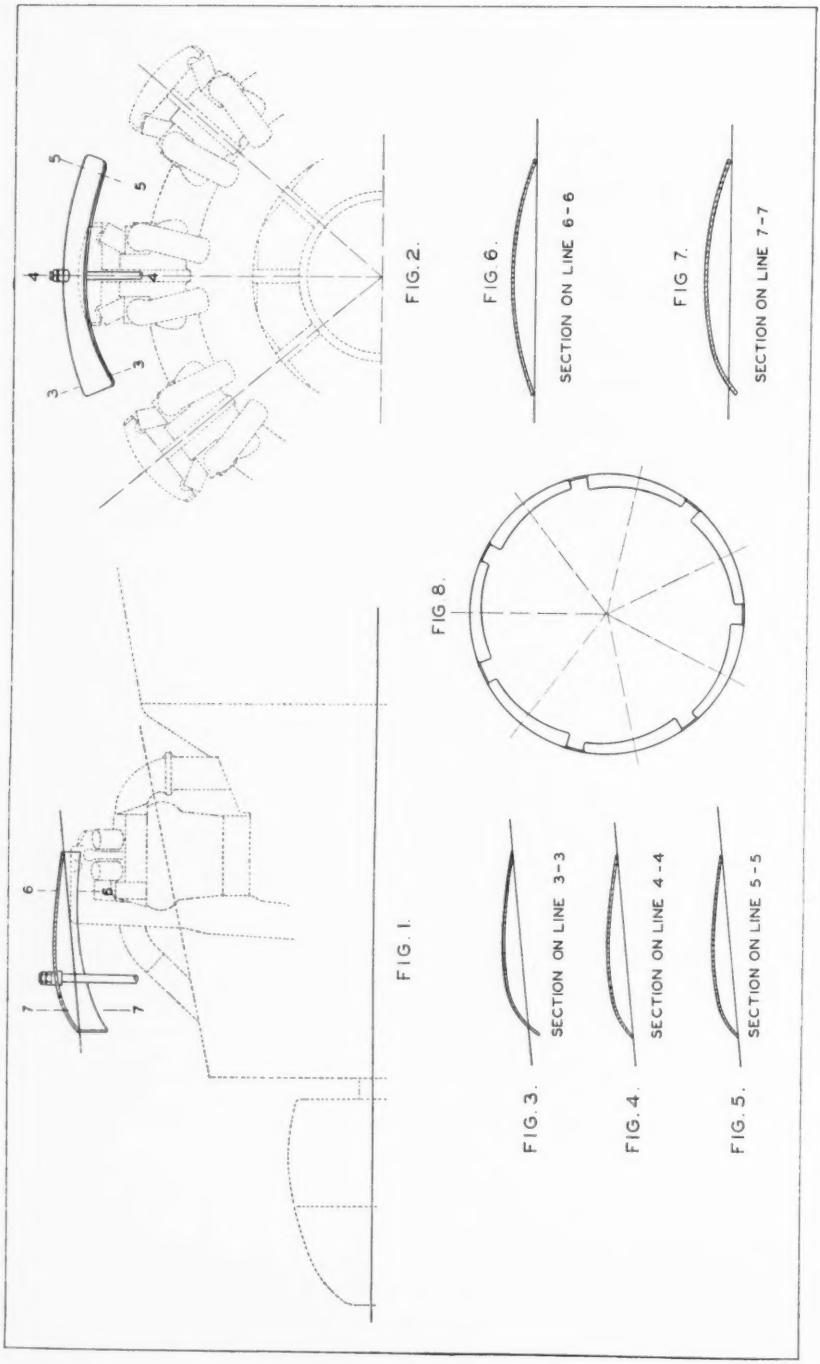
FIG. 1.
FIG. 2.
FIG. 3.
SECTION ON LINE 3-3
FIG. 4.
SECTION ON LINE 4-4
FIG. 5.
SECTION ON LINE 5-5
FIG. 6.
SECTION ON LINE 6-6
FIG. 7.
SECTION ON LINE 7-7
FIG. 8.

cowl or Townend Ring. On the other hand, if such an inclined section is driven or attached to the propeller it will drive the air inwards and backwards over the engine, thus giving a still more powerful forward component whilst keeping the air flow close to the body and preventing turbulence.

A suitably shaped rider similar to the above section impresses upon the radially moving air impinging on it an inward radial force which checks its further outward movement and allows it to flow thence backwards along the contour of the engine or the like.

By rotating the rider or riders at a suitable speed it can be ensured that before turbulence has time to re-form at any peripheral point the next following rider is in position to prevent its formation. Thus by the employment of one or a few riders of negligible weight the effect of a solid flow regulating ring is obtained to achieve the desired result.

By driving the rider or riders at a suitable speed in the opposite direction to that of autorotation they may then act to force air into the space behind the engine so as positively to prevent the reversal of the pressure gradient to which turbulence is largely due.

Fig. 1 is a side view of an autorotating cowl or ring.

Fig. 2 is a front view of Fig. 1, and

Figs. 3, 4 and 5 show respectively sections passing through the axis of the engine.

Figs. 6 and 7 show respectively sections at right angles to the axis of the engine on the lines 6, 6, 7, 7.

The riders may be connected to, or supported by, the airscrew and positively driven.

Also the riders may be connected together, preferably at their rear, by rings of metal so that in effect a louvred or slotted cowl is obtained, which if driven, will force additional air on to the engine, and in fact act as a " blower " to drive the air to any desired direction and correct the pressure gradient behind the engine.

Fig. 8 shows such a power driven or " blower " rotary cowl.

REVIEW

War from the Air

By Air Commodore L. E. O. Charlton, C.B., C.M.G., D.S.O. Published by Thomas Nelson and Sons, Ltd. Price 6/-.

This book is based on a series of lectures, delivered by the author at Trinity College, Cambridge, and is an excellent treatise on air warfare, written from the point of view of a firm belief in the overwhelming potentiality of air bombing.

Air Commodore Charlton believes that the right way to use aircraft in warfare is to bomb, and bomb continuously; that the fighter type of aircraft is almost useless, and that air photography and spotting for artillery are inferior methods of using aircraft which would be much better occupied dropping bombs over the enemy's cities. He regards a bombing formation as a sort of invulnerable flying fortress which cannot be seriously interfered with by any means known to man and which therefore cannot be prevented from destroying anything it pleases. His views on naval matters are similar, as he seems to think that any squadron of battleships is at the complete mercy of any wandering formation of bombers.

It is all to the good that opinions of this sort should be ventilated, but those who read this book must remember that there is a lot to be said on the other side and that the author is too much of a partisan to be strictly fair. Does he really believe, for instance, that the warships in the recent Naval and Air Force exercises off the East Coast of Scotland were really " free to do everything possible to foil the attack " of the hostile aircraft when they were not allowed to use their guns? And why should the bulge be a satisfactory defence against a charge of high explosive in a torpedo and not against a similar charge in an aerial bomb when the bomb explodes alongside the ship?

The book contains much that is of interest to those who wish to understand the potentialities of aerial warfare, but it must be understood that the author's opinions are strictly those of a particular school and that many of great experience can be found who will differ from almost every statement he makes. There seems to be scope for a book which will give the other side of the picture so that the whole case can be judged after hearing the evidence for the defence.

The 584th Lecture delivered before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

A meeting was held at the Royal Society of Arts, John Street, Adelphi, London, on Thursday, November 29th, 1934. In the chair, Mr. D. R. Pye, Member of Council, Deputy Director of Scientific Research, Air Ministry.

The CHAIRMAN: Captain Graham Forsyth was well known to many people connected with aviation. He had had 20 years' experience in the development and construction of many types of aero engines, dating from his service as a member of the Royal Air Force, in the Middle East, during the war. After that he was concerned with water-cooled engine development at the Air Ministry. The more notable of his achievements had been in connection with the three series of Schneider Trophy machines when he was the wet nurse, so to speak, of the successful engine on each occasion. Captain Forsyth had also had a great deal to do with the development of the engines for the airships R.100 and R.101, and has also been directly responsible for the engine for the monoplane which for a while had held the long-distance record by its flight from England to South Africa. Finally, for the last four years Captain Forsyth had been chief designer on the engine side to the Fairey Aviation Company. Thus he had had quite unrivalled experience in various types of engines, particularly in the water-cooled class and they were all grateful to him for coming and giving them the benefit of his experience on the present occasion.

The following paper was then read:—

LIQUID-COOLED ENGINES—DESIGN AND APPLICATION TO HIGH-SPEED AND OTHER AIRCRAFT

BY

CAPTAIN A. GRAHAM FORSYTH

The liquid-cooled engine is generally associated with high speed aircraft, and as I have had some experience in connection with the development of racing engines, when I received the honour of an invitation to read a paper for the Royal Aeronautical Society, I chose this title because it gave me a chance to further the cause of the liquid-cooled engine and to interest you in possible developments of engines suitable for high speed and other types of aircraft.

In attempting to forecast possible developments, I am taking a grave risk, as anything connected with aeronautical engineering is doubtful owing to the rapid changes which take place in a short time, and I can only indicate where I think improvements can take place, based on present progress, and can only hope that my remarks will invite criticism and discussion.

During the paper the " hardy annual " ' frontal area ' will be raised; a slide will be shown of a liquid-cooled engine superimposed over an air-cooled radial of the same b.h.p. This does not mean that I consider the air-cooled engine of no value; on the contrary, I consider it an excellent example of aeronautical engineering, the development of which has been phenomenal. Recent flights have proved that the liquid-cooled engine has a real rival in its air-cooled brother, and that its success will depend upon further development using all known devices to improve its power and to reduce its fuel consumption.

I think that the air-cooled engine, although showing advantages in certain aircraft, may be replaced by the liquid-cooled type when ultra high speeds are required and where high powers have to be developed.

Owing to the great improvements which have been made in air-cooled engine cowling, the difference between the power absorbed by the cowled air-cooled engine as compared with the liquid-cooled type has been narrowed down.

On the latest type air-cooled cowlings, the drag figures are nearly as good as those obtained from a normal water-cooled system, the improvements being somewhere in the neighbourhood of 30 per cent. over installations which were produced two years ago. This means that further improvements will have to be made in the installation of the liquid-cooled type, in order to keep its supremacy over the air-cooled.

The introduction of evaporative cooling systems and the use of ethylene glycol as a cooling medium has had the effect of still further reducing the drag of the liquid-cooled installation, with the result that a gain in performance may still be obtained by converting some types of aircraft to take a liquid-cooled motor.

The characteristics of the liquid-cooled engine are such that the outline can be varied to suit particular installations, and in some cases it has been found possible to totally enclose the engine, with the result that the efficiency of the aircraft has been improved.

The main object of this Paper is to indicate where improvements may be made to increase the power output and to reduce the weight of the engine without reducing the reliability and to improve their installation, thereby providing the aircraft designer with power plants capable of being installed as an integral part of the machine. I propose, therefore, to discuss in detail the following points where I consider improvements may be made:—

(*a*) Generally outline the type of aircraft where I consider a gain would be achieved by installing liquid-cooled engines.
(*b*) Describe briefly the improvements in installation which we may expect due to the introduction of evaporative and glycol cooling systems.
(*c*) Points in favour of liquid-cooled engines.
(*d*) Give a brief description of racing engine development and indicate where the outline of the engines can be modified to suit particular installations.
(*e*) General description of aircraft for various purposes, outlining where the liquid-cooled engine might improve their performance.
(*f*) Reduction in weight due to improved power output and the possible effect of fitting variable pitch airscrews.
(*g*) Possible increase of power for a given cylinder size.
(*h*) Remarks on compression ignition engines and their installation.
(*i*) Fuel injection systems.
(*j*) Brief remarks on two-stroke engines, etc.
(*k*) Air-cooled in-line engines.
(*l*) Starting systems.
(*m*) Cowling.

Aircraft

In 1927 we produced a seaplane, the S.5, fitted with an engine having a capacity of 1,462 cubic inches developing 900 b.h.p., which attained a speed of 319.57 m.p.h., and in 1932 the S.6B., fitted with an engine with a capacity of 2,240 cubic inches, developing approximately 2,200 b.h.p., with a speed of 407.5 m.p.h.

In 1934 we are endeavouring to produce single-seater fighters with speeds approaching 250 m.p.h., whereas with our experience we should be producing bombing aircraft with a speed of 250 m.p.h. and single-seaters of 300 m.p.h.

The United States have produced aircraft for commercial service with speeds up to 220 m.p.h., fitted with air-cooled motors, and it is probable that their performance could be improved by re-considering the type of engine installed.

In the States the increase in speed has been gained by carefully studying the aerodynamic qualities of the aircraft plus a general clean up. Everything is properly streamlined and no projections of any kind are permitted.

The introduction of the retractable undercarriage has also improved the speed.

Generally speaking, the aircraft side of the U.S.A. machines cannot be improved upon a great deal unless there is some revolutionary design change coming along.

Reviewing British aircraft, the construction of which leaves nothing to be desired from a manufacturing standpoint, a great deal can be done to improve the speed by paying greater attention to detail.

We have projecting guns, oil coolers, navigation lamps, bomb racks, all of which require scrapping and which can easily be replaced by producing up-to-date equipment properly streamlined.

The retractable undercarriage also requires developing if we hope to compete against modern aircraft using every known device to improve their speed.

My reason for introducing the foregoing is to establish the fact that it is not worth while considering the engine side unless it is taken for granted that the aircraft into which the engine is going to be installed, will be of an up-to-date type, fully cleaned up in every way and fitted with a retractable undercarriage.

As it is my firm belief that for powers over 700 b.h.p. it may be necessary to revert to liquid-cooled engines, I propose to indicate (under Engines and Installations) where I consider improvements could be made in regard to choosing the right type of engine for various types of aircraft.

Installation (Improvements)

The installation of the liquid-cooled engine has been simplified in recent years. Previously we had radiators on the sides of the fuselage and header tanks in the top plane, and a considerable amount of piping running everywhere in the fuselage.

The raised position of the pilot has enabled a simple installation to be adopted. This consists of a combined header tank and separator large enough to carry reserve water coupled to an underslung radiator.

Four pipes are used to couple up the engine to the radiator and header tank, *i.e.*, pump to radiator (1), engine to header tank (2), tank to radiator (1) (Figs. 1-2), thereby reducing the risk of failure to a minimum.

In my opinion ordinary water cooling will die out and will be replaced by evaporative cooling or ethylene glycol cooling. Experiments in the United States and in this country have proved that by using a standard radiator, the frontal area can be reduced to a minimum without in any way complicating the installation.

The radiator required for glycol cooling is approximately one-third the size of a water-cooled radiator designed for English summer conditions.

Oil cooling has to be improved as the high temperature of 130°C. at which the engine is operating raises the oil temperature considerably.

Approximately 2½ per cent. power is lost due to the engine running at high temperature.

On the other hand, there is a great deal to be said in favour of evaporative cooling, using wing condensers, as their introduction eliminates all drag. It has been demonstrated that there is very little steam lost when the condenser is punctured by gun fire.

I have come to the conclusion that for future aircraft evaporative cooling or glycol cooling will have to be used as the radiator size required to cover a water-

cooled system under full tropical summer conditions is prohibitive and eliminates all prospects of producing fast aircraft.

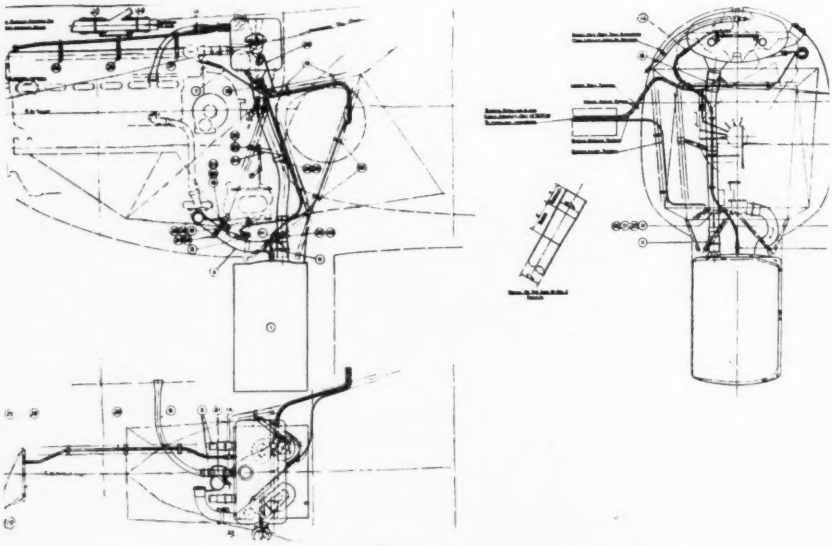

FIG. 1.
Water system, 19/27 "R.R." Engine.

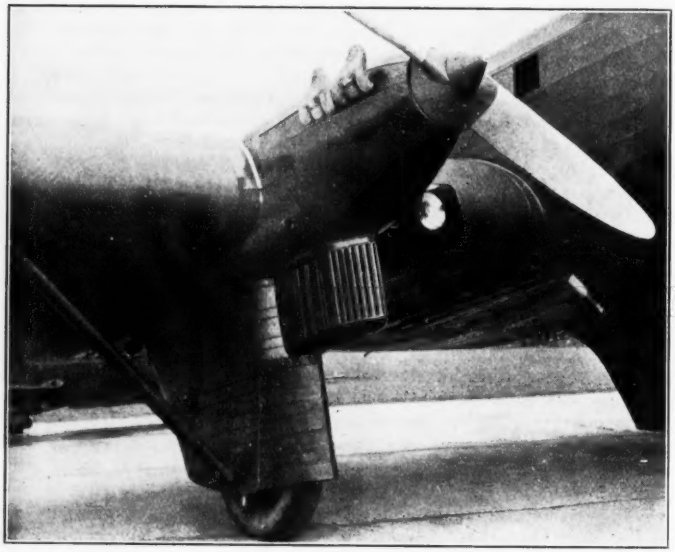

FIG. 2.
19/27 radiator mounting.

Points in Favour of Liquid-cooled Engines

(*a*) The design allows a small engine to be installed in the best fuselage shape, thereby reducing the frontal area to a minimum.

(*b*) When used in conjunction with a suitable cooling system the drag, due to the engines, is reduced to a minimum.

(*c*) When tandem engines are used the engines will function equally well as pushers or tractors.

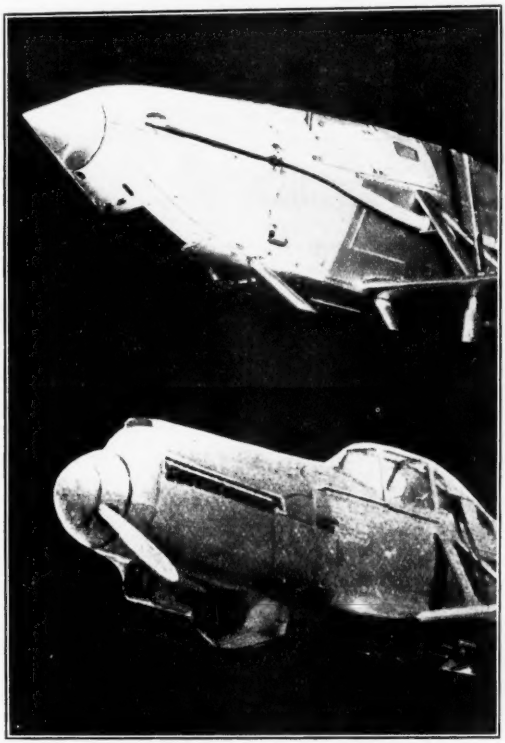

FIG. 3.

Curtiss A.8 "Shrike," S.9/30 engine nose.

(*d*) Engines can be fitted with reduction gears enabling the airscrew shaft to be located in the best possible position relative to the engine shaft, thereby producing the best cowling lines, Fig. 3. (Fig. 3 also shows how a liquid-cooled engine should not be installed. The engine shown is direct drive and it will be seen that a vast improvement can be made by locating the airscrew shaft in the correct position.)

(*e*) The construction of the airscrew shaft and drive makes it possible to house the operating gear for a variable pitch airscrew inside the engine, Fig. 4.

In certain cases it is possible to arrange for a gun to be fired through the airscrew shaft bore.

(*f*) The engine speed is not so limited as on the air-cooled radial engine, thereby making it possible for the engine to be run at high speeds developing high powers from low cylinder capacity.

(*g*) Owing to the high speed, it is possible to run with high compression ratios resulting in economical fuel consumption.

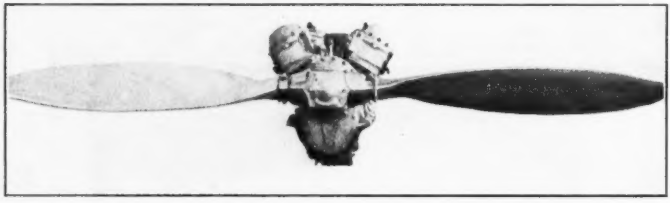

FIG. 4.

Front view, liquid-cooled engine with controllable pitch propeller.

(*h*) Oil consumption is difficult to control in any high speed engine, but the liquid-cooled engine scores, due to it being possible to adopt a lower piston clearance than is generally used in air-cooled engines. It is possible, however, that when glycol cooling is used, the clearances will closely follow those used in air-cooled motors.

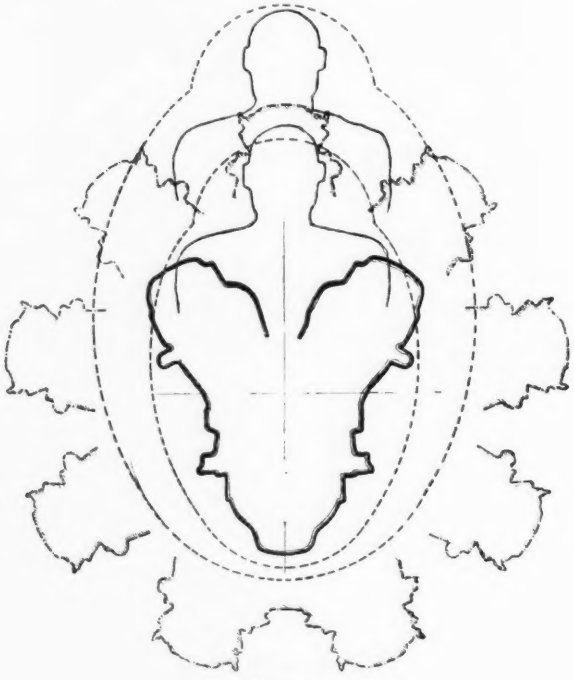

FIG. 5.

Pilot's view, comparing liquid- and air-cooled engines.

(*j*) Liquid-cooled engines are generally lighter than radial air-cooled types developing the same power. This is mostly accounted for by it being possible to use a high compression ratio and higher speeds, thereby reducing the engine size, due to the cubic capacity of the cylinders being smaller than those required for the air-cooled type.

(*k*) In large aircraft the coolant can be used for heating purposes, providing additional comfort for the passengers in commercial aircraft.

The introduction of this method of heating reduces fire risk and also all danger of poisonous fumes entering the passenger cabin.

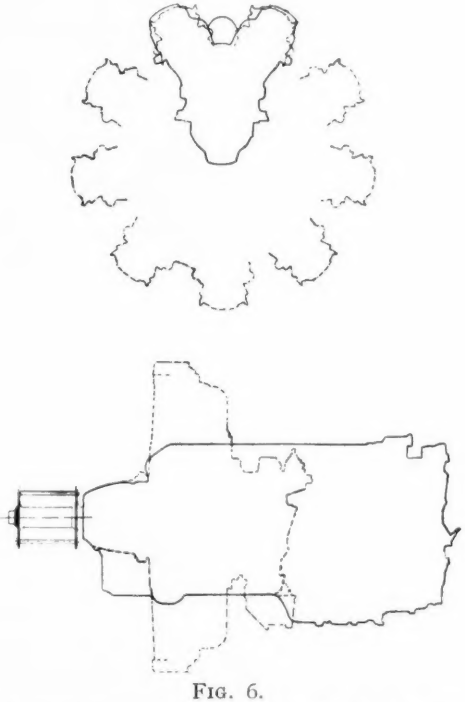

FIG. 6.

Frontal area comparisons, liquid-cooled and air-cooled.

(*l*) In large flying boats where auxiliary sets are installed for lighting, pumping, etc., these can be liquid-cooled and coupled to the main cooling system, thereby providing a means of keeping the main engines at a temperature to prevent freezing, and to enable a quick start to be made in an emergency, the lubricating oil being kept at a temperature by immersion heaters in the oil tanks.

(*m*) The engines can be installed inside the fuselage or wings, which will enable power plants to be installed in large aircraft in such a position that the engine will be accessible in flight.

(*n*) The engines are more silent in operation than air-cooled, due to the jacketing of the cylinders damping out internal noises. In addition, the totally enclosed valve gear is quieter.

Taking the installation as a whole, including fuel and oil and coolant, with a given duration, there is very little in the all-up weight of the aircraft. The liquid-cooled engine, however, scores when the duration is over five hours.

Engines and Installations

Let us assume that the present aeroplane as we know it is the best method of wasting power, and that the only known method adopted of gaining speed is to fit larger engines and still larger as they come along, whereas if the apparatus as a whole is considered carefully, the speed can be increased by careful design of the aeroplane combined with the installation of a suitable engine without going to enormous powers.

De Havilland's have proved this by producing the " Comet " and " Dragon " with small in-line air-cooled motors installed.

It is interesting to note that the above aircraft, although they are for commercial purposes, are faster than some of the single-seater fighters fitted with engines developing over 500 b.h.p.

Fig. 5 shows the relative sizes of a pilot, a liquid-cooled engine, and an air-cooled engine, the engines being of 600 b.h.p.

Fig. 6 shows the two engines superimposed.

It will be noted that the back view of the pilot closely conforms with the end view of a 60° " V " engine, and that the head projects sufficiently high above the engine to provide a good view, whereas with the air-cooled radial, the pilot is blanked out unless the seat position is raised.

The gun position is simplified by the use of the " V " type, as they can conveniently be placed alongside the engine at the base of the cylinder blocks, and in addition, in certain engines, a third gun can be arranged to fire through the airscrew shaft.

It is difficult to mount guns to fire past the radial air-cooled motor, unless they are installed in a fuselage of large cross section. Generally, for air-cooled engines, the fuselage is large in cross section to allow of a suitable cowling arrangement being adopted.

As we are out to produce a fast aircraft, it is obvious that a much smaller fuselage can be constructed behind a 60° " V " engine than is possible with the air-cooled radial.

It will be pointed out that the modern equipment called for demands a large fuselage, but if due consideration is given to the equipment to be carried in a single-seater fighter, it is possible to instal it in a small fuselage suitable for the 60° " V " engine.

The choice of engine to be installed will be decided by the function of the aircraft and also by taking into consideration the climatic conditions.

Small Private and Commercial Aircraft

I think that it will be generally agreed that for aircraft constructed for the above purposes that small air-cooled in-line engines are most suitable. They can be accommodated in front of a small fuselage and at the same time allow the pilot to have a good view.

In my opinion the small radial is not so good, particularly in single-engined aircraft, as the view obtained is bad compared with that of an aircraft having an in-line engine installed.

It is probable that at some future date the fashion may change and that an in-line liquid-cooled motor will be used. This will have the effect of making the small aircraft a de luxe type, with a silent engine, giving still greater comfort to the pilot and passengers.

Fig. 7 shows a small passenger machine fitted with an air-cooled radial engine. Fig. 8 shows how the fitting of a liquid-cooled engine would improve

the view and speed of the aircraft. The engine is glycol-cooled with wing condensers.

Racing Aircraft and Engines

At present nearly all the high speed records are held by aircraft having liquid-cooled engines installed.

In cases where high speeds have been obtained from aircraft with air-cooled engines, they have been of modern design compared with the types used in obtaining the high speed records. I think that higher speeds could be obtained out of these aircraft if liquid-cooled engines were installed. This view, I believe is recognised in the States, and it is probable that we shall see a change over to liquid-cooled engines in certain American racing and fighting aircraft in the

FIG. 7.
" Airspeed Courier," air-cooled.

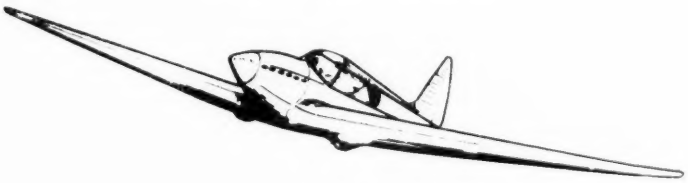

FIG. 8.
" Airspeed Courier," water-cooled.

near future. They have already produced a fighter with a glycol-cooled engine, which shows a considerable gain in speed over the air-cooled engined aircraft, although the power of the liquid-cooled engine is lower, proving that there is something to come by cleaning up the nose of the aircraft.

Engine Outlines

From a development standpoint a liquid-cooled engine gives greater scope and also the shape of the engine can be modified to suit the particular installation.

Taking the " Lion " and " R " engine as examples, it will be seen that the cylinder blocks have been formed to blend in with the cowling lines, and that when the engine is installed it becomes a streamlined part of the nose.

The " broad-arrow " engine is more difficult to instal than the 60° " V," due to the exhaust pipes on the centre block interfering with the air intakes and also with the slipstream over the block. Further, the installation makes it

most uncomfortable for the pilot, as the exhaust fumes blow back into the cockpit. In certain instances it was found necessary to fit special apparatus in the cockpit to prevent the pilot from being gassed.

The " Lion " engine has a capacity of 1,462 cubic inches (23.95 litres). This engine originally developed 400 b.h.p. By modifying the design and by raising the compression ratio to 10/1, and the speed to 3,200 r.p.m., the power was increased to 900 b.h.p., which equals 37.57 b.h.p. per litre.

Particular note should be made of the consumption of this engine, which equalled .432 pints, using 50 per cent. Swan fuel with 50 per cent. standard Aviation fuel plus 8 c.c.'s per gallon/tel.

The low consumption obtained enabled the all-up weight of the aircraft to be reduced to a minimum for racing purposes.

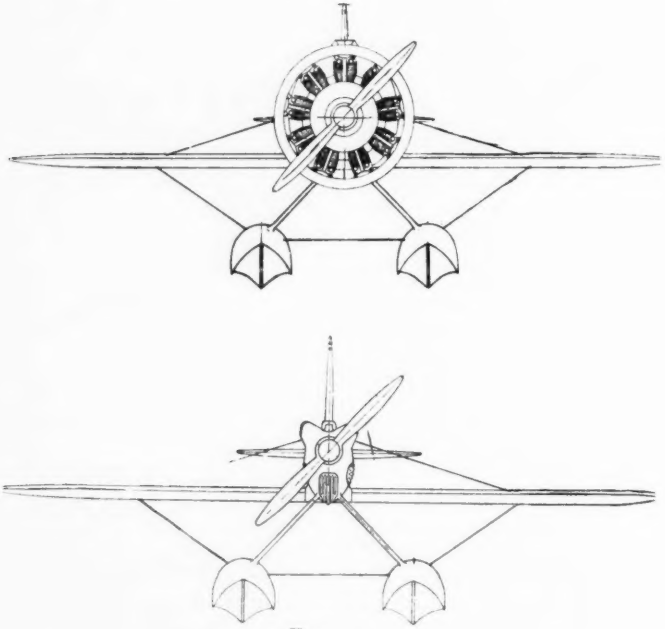

FIG. 9.

S.6 water-cooled and air-cooled, front view comparisons.

The supercharged engine which was fitted into the Gloster VI developed 1,350 b.h.p., which equals 56.35 b.h.p. per litre.

Coming to the " R " engine, this has a capacity of 2,240 cubic inches (36.70 litres). This engine developed 2,200 b.h.p. = 59.94 b.h.p. per litre. At a later date the power was raised to 2,600 b.h.p. = 70.84 b.h.p. per litre.

The twin " F.I.A.T. " engine also develops approximately the same b.h.p. per litre.

It has been predicted that air-cooled engines of the future will develop 40/50 b.h.p. per litre, which is well below that of the present-day liquid-cooled racing engine.

Fig. 9 shows the front elevation of the S.6B., together with a view of the same aircraft fitted with an air-cooled engine taking into consideration the maximum improvement predicted.

Fig. 10 shows the side views of the aircraft.

During the development of racing engines, shapes other than the " broad-arrow " and 60° " Vee " were considered. They had to be dropped, due to it being impossible to produce and develop a new shape of engine in time to compete in the various races. It might be of interest to my listeners briefly to describe some of the types considered.

The " Gloster " (biplane) had the top planes faired into the cylinder blocks of the " Lion " engine. The view was bad but it was found that the construction did increase the speed compared with the earlier aircraft fitted with the standard top wing.

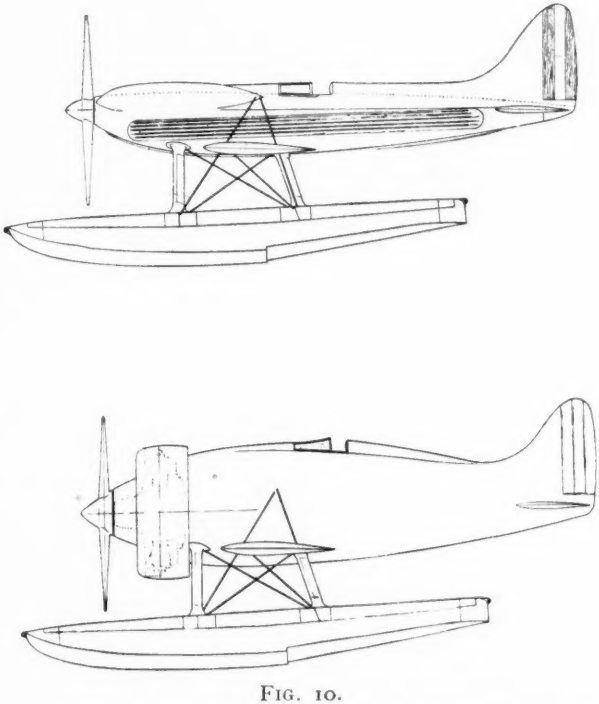

FIG. 10.

S.6 air-cooled and water-cooled, side view comparisons.

Fig. 11 shows a further development of the scheme applied to a low-wing monoplane, and Fig. 12 to a high-wing monoplane.

The engine was to be constructed with three blocks of six cylinders spaced at 120° round the crankcase. This arrangement allowed two of the banks to be faired into the ends of the wings, thereby eliminating the area of two projecting cylinder blocks when applied to a monoplane; thereby reducing the drag to a minimum.

It was found that the view would not be too good, but that a gain in speed of 20 m.p.h. would be obtained due to the reduced head resistance.

The low-wing type still had the objectionable exhaust system on the centre block, in line with the pilot's head. The reversed engine shown at Fig. 12 was considered the best installation out of the two, although the gain in speed was reduced slightly due to the centre block projecting underneath the nose.

There are considerable difficulties in producing such an engine, as the crankshaft has to be inserted through the end of the crankcase.

An inverted " Vee " engine was also considered, but this had to be ruled out due to excessive weight and the difficulty in mounting the engine in the air-frame.

It will be appreciated that the engine weight was considerably increased due to the layout of the auxiliaries. The oil filters and pumps have to be carried in the V. ; also the scavenging arrangements are difficult. Pumps have to be fitted to keep the camcase covers dry.

The estimated increase in weight was 50lbs. Further, the frontal area was increased, due to the engine being inverted.

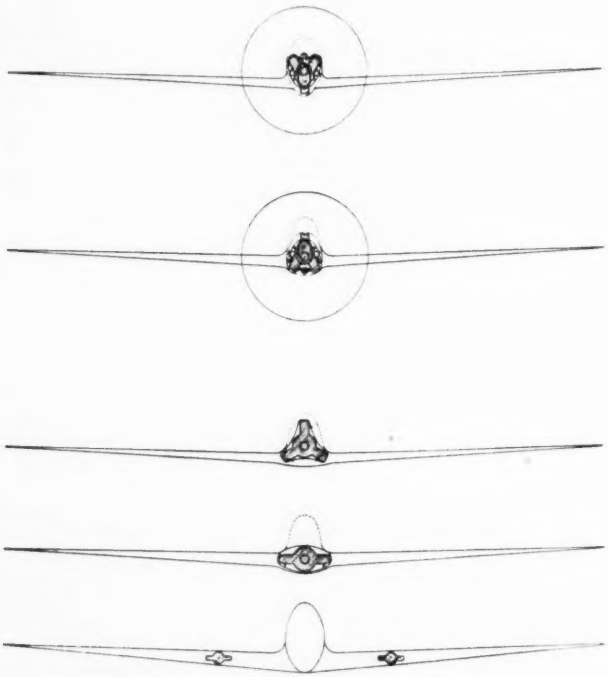

FIG. 11.

Frontal area, various types of engines.

Regarding the mounting, the only method which appeared to give any promise was to extend the rear end of the crankcase to form a ring suitable for mounting on to the fuselage front end. This made the crankcase casting very complicated, and there were doubts about it being possible to obtain the required strength in the magnesium casting without still further increasing the weight.

Delage have produced an engine mounted as described.

Investigations into the horizontally opposed engine were most interesting, as it was found possible to produce a flying wing. The engine considered was 16-cylinder type, having two banks of eight cylinders set at 162°; this angle gave the correct firing sequence.

The angle of the cylinders conforms with the dihedral of the planes.

It was proposed that the pilot should be in a prone position in the aircraft, and that the engine should be installed in front of the main plane. (Fig. 11 shows a front elevation of the aircraft.) This gave easy access to the engine and allowed the exhaust to be taken from the underside of the blocks. This would have produced a really fast seaplane, and when fitted with a retractable undercarriage, as a landplane, it would, virtually speaking, become a flying wing.

Single-seater Fighters

The function of this aircraft is to carry a gun and the pilot to its maximum ceiling in the shortest time, which can have a reasonable duration (approximately $3\frac{1}{2}$ hours).

It is my opinion that the racing engine of to-day should become the Service single-seater fighter engine of to-morrow, and that the question of vulnerability should not be over-stressed.

The single-seater fighter should not be a target for fast commercial aircraft, but should be a machine capable of outflying any known type. At present, air-

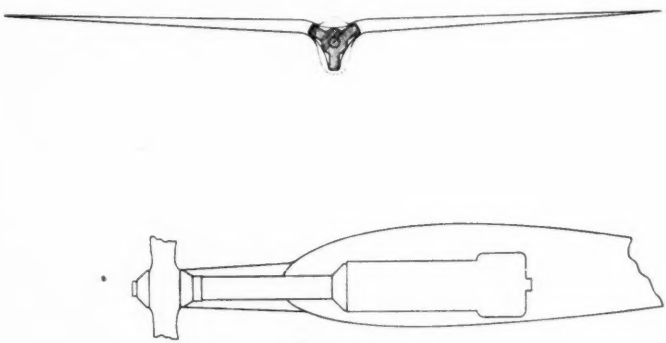

FIG. 12.

Horizontally opposed C.I. engine mounted in wing.

craft for this purpose are not fast enough to catch up with the modern commercial aircraft, such as the "Douglas," etc.

At present the development of the single-seater fighter engine is crippled by type test conditions, and due to it being necessary to instal universal types of engines which can be used in heavy bombers when required, whereas if the engines were solely considered for this purpose, they could be reduced in weight and also would develop higher powers for a given capacity.

Racing engines have to pass a test of one hour's duration at full throttle, and if developed to run at 2/3 power, would pass a 50 hours' type test. At present they have to undergo a full type test of 100 hours, compared with the 50 hours' test required for civil engines.

As the general duration of flight is $3\frac{1}{2}$ hours, it would improve the performance of the aircraft if the type test was reduced to civil duration, plus the necessary high speed, maximum r.p.m., etc.

Auxiliaries should be reduced to a minimum, and the method of starting should be standardised. (At present engines used for this purpose have provision made for at least three types of starting, which considerably increases the weight.)

Two-seater Fighters

The engines for this type of aircraft should be similar to those required for the single-seater types.

Day Bombers

Owing to the larger duration of flight of this type of aircraft, it will be necessary to complete a full Service type test on the engines being installed.

Large Commercial Aircraft

The recent flight of a " Douglas " aircraft to Australia, has proved that it is possible to produce fast commercial aircraft without having to resort to

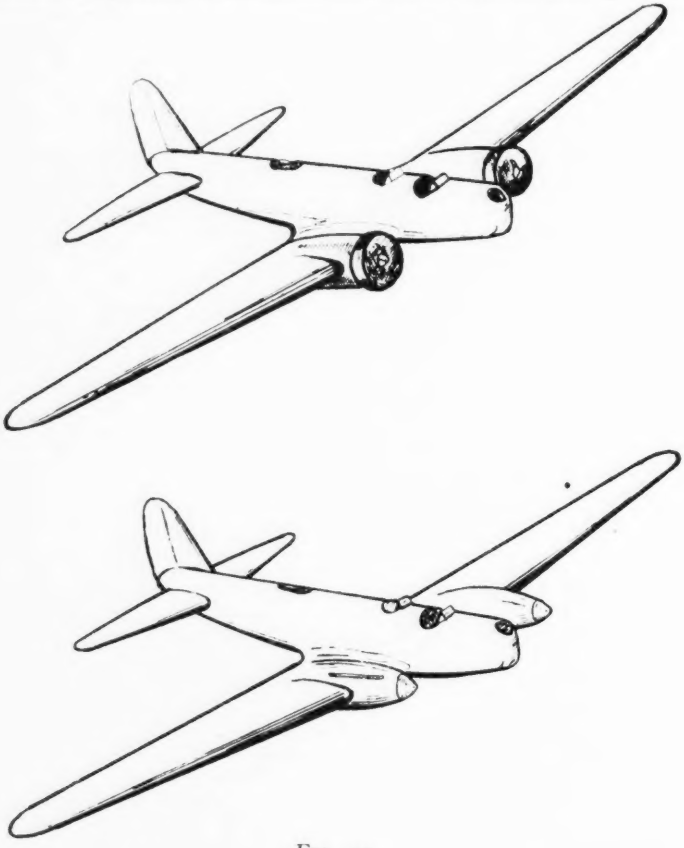

FIG. 13.
Boeing air-cooled and water-cooled comparisons.

more than two engines, capable of travelling at approximately 220 m.p.h. I think you will agree that this excellent performance has been achieved by producing an aircraft of clean design combined with the use of variable pitch airscrews and retractable undercarriages. The engines develop 750 b.h.p., a total of 1,500 b.h.p., and during flight at 200 m.p.h. run under cruising conditions. This performance is better than we obtain from some of our single-seater fighters.

The two engines have a frontal area of 23 sq. ft., and are well cowled in, the nacelles being mounted on the wings in a position taking full advantage of the cowling.

Note.—The frontal areas quoted are the actual projected areas, and in considering the application of engines which will be referred to later on in the paper, it must be assumed that it is intended to allow the usual drag factors comparable with the type of cowling used on the particular engines installed.

I think that the performance might be further improved by installing liquid-cooled engines, as the combined head resistance of the engine and radiator would be reduced to 12 sq. ft., 4 sq. ft. being required to cover the radiators suitable for glycol cooling. The remaining 8 sq. ft. can be cowled into streamlined nacelles totally enclosing the engines.

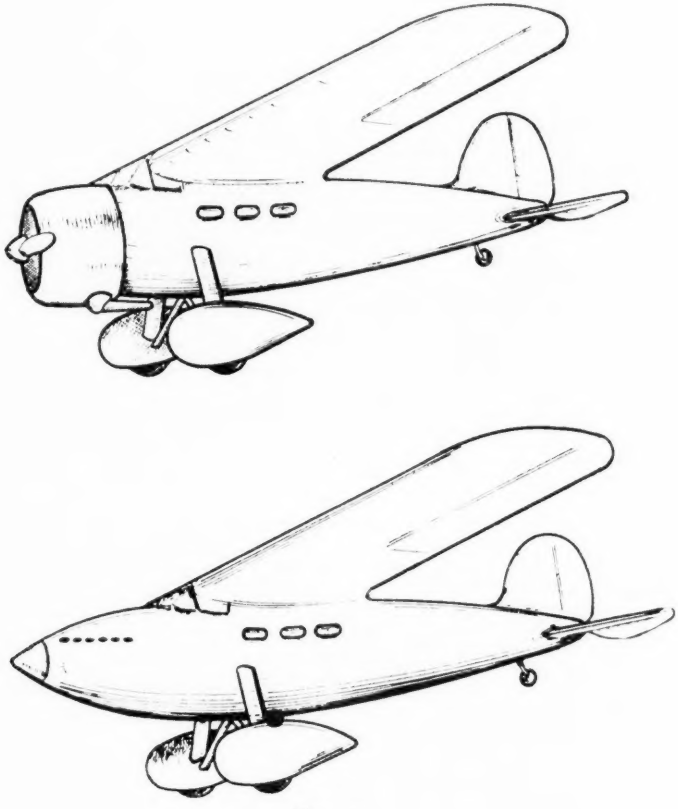

FIG. 14.

Lockheed air-cooled and water-cooled comparisons.

It is obvious that a gain in speed would be achieved by the conversion due to the reduction in area from 23 sq. ft. to 12 sq. ft. I should estimate a gain of from 5 to 10 per cent., according to the type of installation.

Figs. 13 and 14 show examples of two types of aircraft converted from air to liquid cooling.

Comparing the " Douglas " with our commercial aircraft, it is obvious that a great deal can be done to improve their speed by reconsidering the application of engines to the airframe.

In cases where four engines are installed, say of 600 b.h.p., if air-cooled they would have a frontal area of 47.2 sq. ft., whereas, if liquid-cooled engines in tandem could be used, the area would be reduced to 14 sq. ft.

The " Short " flying-boat, Fig. 15, is a good example of this installation. It is difficult to imagine how such an installation could be carried out using air-cooled engines, as the total power developed is 4,800 b.h.p. at normal r.p.m.

The engine and radiators have an approximate frontal area of 24 sq. ft. (this can be reduced by using glycol cooling).

Assuming a frontal area of 12 sq. ft. for a radial engine, if tractors were used, the total area would be 72 sq. ft., and if tandem engines were possible, 36 sq. ft., a gain of 50 per cent.

I therefore consider that liquid-cooled engines, particularly when glycol-cooled, will enable speeds to be increased without effecting reliability, and will, in addition, reduce the all-up weight due to the reduced fuel and oil consumption.

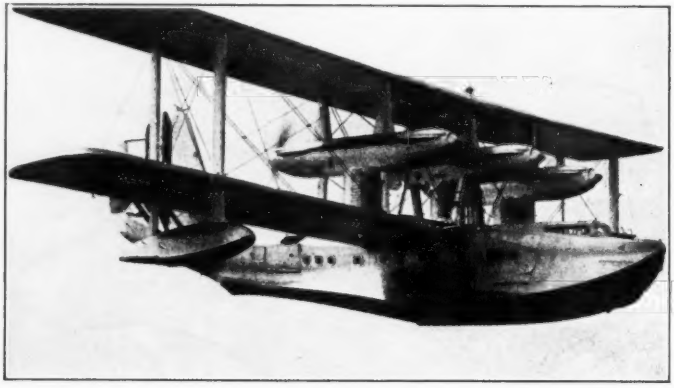

FIG. 15.
Short R.6/28 flying boat.

C.I. Engines

A great deal of publicity has been given to compression ignition engines (Diesel). These will, in all probability, come into use in long-range aircraft. At present, the engines are much heavier per b.h.p. than the petrol type developing the same power, but in aircraft with a duration over 7½ hours, the additional weight of the engine is compensated by the reduced weight of fuel which has to be carried to cover the whole flight.

In their present form the only installation which appears to be practical is in large commercial single-engined aircraft having the engine installed in the nose of the fuselage, as the height of the engine and the width of the mounting marries up particularly well with the front end of a large fuselage. If, however, it is essential to provide engines installed in the wings, the present form could be modified to provide a better installation.

Figs. 16-17 show the dimensions of the " Jumo " engine compared with a petrol engine of the same b.h.p.

For multi-engined aircraft, the engines can be accommodated in deep sectioned wings in conjunction with a shaft extension as shown on Fig. 12. This would allow the engine to be installed on its side in the wing section and would locate the airscrew in front of the leading edge in an efficient position. Some difficulty would be experienced in obtaining the required ground clearance for the airscrew when installed in flying boats.

The shaft extension would again raise the all-up weight of the complete installation.

Large Bombing Aircraft

At present our bombing aircraft can be out-distanced by certain civil aircraft. These aircraft could, in an emergency, be converted to bombers. Improvements

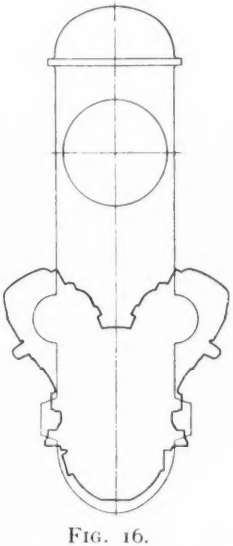

FIG. 16.
Frontal area, liquid-cooled (petrol) and "Jumo IV" C.I. Engine.

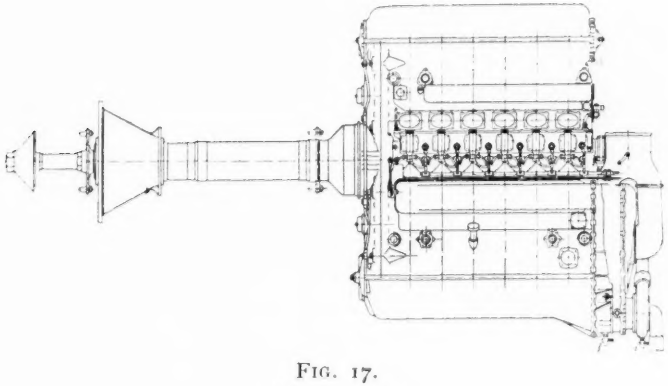

FIG. 17.
"Jumo IV."

could be made in their engine installation, but to take full advantage of such an improvement, the aircraft must be designed on modern lines.

In my opinion the most suitable engine for this purpose is the 60° "Vee" liquid-cooled engine, as the installation is simple, and due to the large wing areas

used there is no difficulty in providing a simple glycol cooling system or an evaporative system using wing condensers.

My remarks upon the installation of engines in large commercial aircraft apply to bombers. Variable pitch airscrews are essential for both types of aircraft.

A great improvement in take-off can also be obtained by using a multi-speed supercharger combined with the use of a variable pitch airscrew.

Large Flying Boats

Fig. 15 shows an excellent example covering the installation of liquid-cooled engines in tandem in a flying boat. It will be observed that everything has been

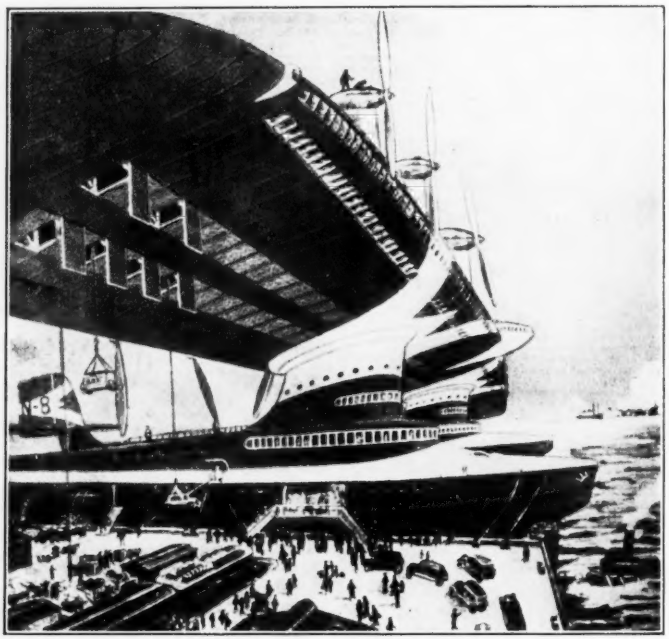

FIG. 18.

Telegraph sketch, large flying boat.

done to reduce the drag due to the engines, and that the engines are accessible. The frontal area of the six engines is approximately 24 sq. ft. for a total of 4,800 b.h.p., whereas, if air-cooled engines were installed, the area would be increased to 50 sq. ft., using tandem engines, and if single engines were used as tractors, 100 sq. ft.

In large monoplanes the " Vee " engine still scores, as the engines have to be mounted above the wing to provide airscrew clearance. This means that the engine nacelle has to be supported above the plane by a streamline section carrying the mounting. When liquid-cooled engines are installed, radiators can be mounted underneath the engine in the streamline section without increasing the drag.

Compression ignition engines can be installed as described for large commercial aircraft.

Figs. 18 and 19 show the design of a large flying boat capable of crossing the Atlantic. Probably such a boat may be built at some future date. This type of aircraft will bring the compression ignition engine into its own as the engines will have to be built into power houses to enable repairs to be carried out in flight.

The engines will have to be liquid-cooled and many advantages are apparent by using this type of engine, as the heating arrangements, etc., will be considerably simplified.

Airship Engines

Tandem " Vee " engines were installed in R.100 (petrol). This produced a small engine car, but it was found that the engines were most inaccessible during flight.

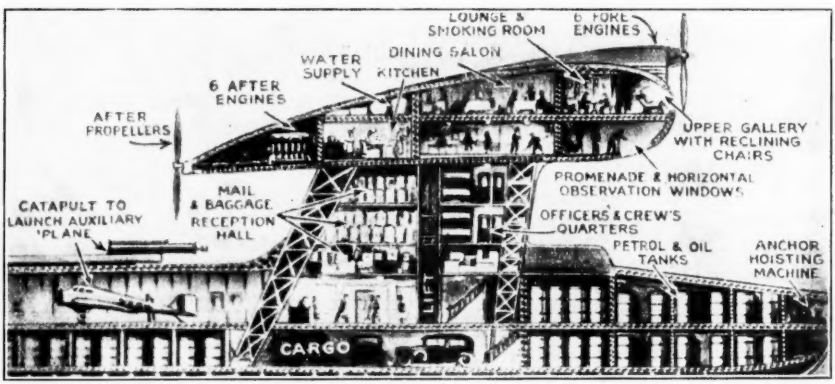

FIG. 19.

Telegraph sketch, large flying boat.

In R.101 eight-cylinder in-line engines were used, mounted in large power cars arranged so that the operator had access to the whole of the engine in flight. In this particular instance it was worth while to raise the size of the engine cars at the expense of increasing the drag, as the combination of the eight-cylinder in-line engine and the large car, made it possible for the connecting rods and pistons, cylinder heads, etc., to be removed in flight. Many occasions arose where this work had to be carried out; the use of the large car was fully justified.

If at some future date, it is decided to proceed with further airship construction, the best type of engine to develop will be a geared compression ignition engine of the in-line type. Admittedly, the engines installed in R.101 were too heavy, but if further development was continued on this type of engine, there is no doubt that the weight power ratio could be reduced to somewhere in the neighbourhood of 3½lbs. per b.h.p.

The chief problem to be solved is the construction of the crankcase. I think that the introduction of a balanced crankshaft would definitely overcome the troubles previously experienced in this direction.

Engines of the " Jumo " type would be difficult to instal, as it would not be possible to withdraw the lower crankshaft and pistons underneath the engine unless the power cars were made exceptionally deep. There is, of course, the possibility that for future aircraft, the engines will be mounted in centralised power cars having the airscrews driven by shafting and gearing. This installation would make it possible to use practically any type of liquid-cooled engine.

For airship engines, to ensure that they were tested for reliability, the type test should be extended to at least 500 hours.

Future Development

The introduction of the variable pitch airscrew may enable improvements to be made in engine performance, as it will give the engine designer greater scope and will also tend to reduce the weight power ratio of the engine, taking into consideration the increased weight of the hub and mechanism.

At present engines have to be tested as follows:—

Normal Speed.—90 hours endurance power.

Maximum Speed.—1 hour at maximum boost.

5 *per cent. Excess Max. Speed.*—1 hour at not more than 30 per cent. normal.

20 *per cent. below Normal r.p.m. under Take-off Conditions.*—9 hours' duration at maximum boost.

T.V. Dive Conditions.—30 per cent. in excess of normal r.p.m. Approximately 1 hour.

Additional High Power Test.—¼hr. at max. perm. speed with pressure in induction pipe to be 1lb. sq. inch excess of M.P.B.

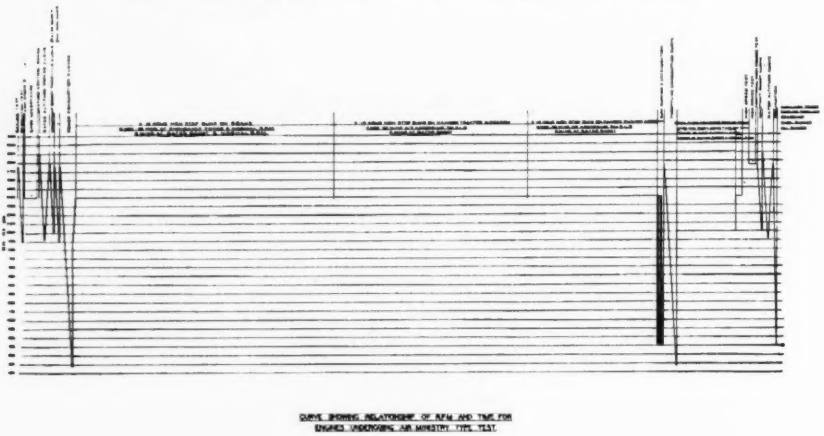

FIG. 20.

Curve showing relationship r.p.m. and time for test engines.

Taking a normal speed of 2,400 r.p.m., this gives a speed range of 1,900 r.p.m. take-off, 2,400 normal, maximum r.p.m. 15 per cent. above normal, 2,760 high speed 2,900 r.p.m.; T.V. dive 30 per cent. above normal = 3,120 r.p.m. At 1,900 r.p.m. the engine has to stand maximum boost, generally plus 3lbs. in excess of normal boost, and at 3,120 r.p.m. as low a b.h.p. as possible, which means that the engine has to be built heavy enough to withstand the high m.e.p.'s at 1,900 r.p.m. and the high inertia loading at 3,120 r.p.m. Fig. 20 shows a typical curve of the above test.

The use of the V.P. hub simplifies the tests, as these tests will be carried out at a given speed with probably a 5 per cent. maximum speed.

The T.V. dive conditions and also the take-off conditions will be eliminated.

These new conditions will allow the compression ratio to be raised, improving the power and fuel consumption, also the normal speed can be raised to somewhere approaching the original maximum r.p.m.

The following shows the improvement which I consider could be made to an existing engine without modifying the construction with the exception that the supercharger capacity would have to be raised to cover the increased power output and to maintain its existing rated altitude.

The engine will be fitted with a variable pitch airscrew governed to control the r.p.m., the boost control to be continually in action during the whole period of the engine running.

Under present conditions the engine has a speed range from 2,000 r.p.m. to 3,250 r.p.m.; these speeds covering the take-off r.p.m. and T.V. diving conditions.

The normal rating of the engine is 600 b.h.p. at 2,500 r.p.m., and under take-off conditions at plus boost develops 700 b.h.p. for take-off at 2,240 r.p.m.

The b.m.e.p. under the two conditions = 191 and 146, the mean b.m.e.p. being 168.5.

With the controlled V.P. hub fitted, the speed of the engine could be raised to 2,700 r.p.m., and with an m.e.p. of 168.5 would develop 740 b.h.p., being a gain of 140 b.h.p. over the power obtained at the present normal r.p.m.

It will be noted that, under the revised conditions, there is a gain in take-off power due to the higher r.p.m. with airscrew at minimum pitch, and that there is also a similar gain on the climb and in level flight.

Under type test conditions it is suggested that the engine would satisfactorily get through a test at nine-tenths of 740 b.h.p., at 2,700 r.p.m., and that if a 5 per cent. increase was imposed to cover over-revving, this would still be under the existing maximum r.p.m. (3,120), 5 per cent. excess being 2,835 r.p.m.

At present the weight power ratio of the engine is 1.6lbs. at normal power. This would be reduced to 1.31lbs. per b.h.p., allowing an additional 30lbs. weight for the over-size supercharger.

Increase in Power

During the last few years the liquid-cooled engine has been extensively developed, with the result that the b.h.p. per litre of cylinder capacity has been raised from 22.6 to 28.3 b.h.p. per litre at normal power. This improvement has been gained by (*a*) increasing the engine speed, (*b*) increasing the boost pressure, and (*c*) by the introduction of 87 octane fuel.

So far advantage has not been taken in raising the compression ratio, but it is possible that this development will be introduced at an early date.

At present the 87 octane fuel does overcome detonation under take-off conditions, but immediately the variable pitch airscrew becomes standardised it will be possible to take greater advantage of the fuel by raising the compression ratio owing to the increased speed at which the engines will be run. The b.h.p. per litre developed by standard engines is much below that obtained from racing engines. As previously stated, the unsupercharged " Lion " engine developed 37.57 b.h.p./litre, and, when supercharged, 56.35. In the case of the Rolls-Royce " R " engine, at 2,200 b.h.p., 59.94 and at 2,600 b.h.p. = 70.84.

Comparing the present liquid-cooled engine with existing radial engines, the cubic capacity of a liquid-cooled for 600 b.h.p. averages 21.2 litres, and in the case of the radial engine 29.5 litres, the power developed by the liquid-cooled engine being 28.3 b.h.p. per litre, and in the case of the air-cooled radial 20.4 b.h.p./litre.

By making use of the improvement in fuel, and also due to it being possible to increase the r.p.m., I consider that it would be possible to produce an engine for installation in single-seater fighters having a capacity of 1,600 cubic inches (= 26.2 litres), developing 1,000 b.h.p. at 3,000 r.p.m., at an m.e.p. of 170 for an all-up weight of 1,000lbs.

These figures do not come up to the racing engine standard, but represent what would appear to be a safe indication of the development which will take place on the liquid-cooled engine during the next two or three years.

Some of the small racing car engines in the 1½ litre class develop up to 160 b.h.p., at 7,000 r.p.m. These engines are fitted with positive superchargers and run on exceptionally high compression ratios on alcohol fuel. The m.e.p. obtained is somewhere in the neighbourhood of 200lbs./sq. inch.

I have actually seen an engine running under these conditions. A few details of the construction might be of interest. The four cylinders 63 m/m. bore by 120 m/m. stroke were steel jacketed, wet liners, having four valves per cylinder, operated by two direct action cams driven by spur gearing on the end of the engine crankcase. The supercharger was of the Rootes type. The crankshaft was mounted on roller bearings, and the connecting rod big ends were mounted on needle rollers in split housings.

The introduction of the split housing is unusual, but it was found that the bearing ran satisfactorily provided the joint between the halves of the housings were properly backed off in the direction of rotation. The compression ratio was 12 to 1.

Mr. Millar, of Dusenberg fame, has, I believe, constructed a 16-cylinder " Vee " engine using small cylinders running at 5,000 r.p.m. The results obtained from this engine are not available, but it does indicate that in the States they are investigating the possibility of producing high speed aero engines of small cubic capacity.

In this country we have the Napier " Dagger " air-cooled which has 24 cylinders running at 4,000 r.p.m. This engine develops 630 b.h.p. at 3,600 r.p.m., which equals 37.3 b.h.p. per litre, and at 4,000 r.p.m. develops 690 b.h.p., which equals 41 b.h.p. per litre. This output is much higher than has been obtained from any other type of aero engine, apart from racing engines built in this country.

As already indicated, I consider that the present power developed by aero engines is still capable of improvement and it is possible that the b.h.p. previously developed by the racing engines will gradually be introduced into the Service types. This will only be possible if the engines are studied solely for the particular purpose for which they are going to be used.

The " Hispano-Suiza Y. Brs." engine is interesting, as apart from racing engines, it has the lowest weight power ratio of any water-cooled type. This engine has a capacity of 36 litres and develops 860 C.V. (846 h.p.) at 13,000ft. at 2,400 r.p.m., which equals 23.9 C.V. per litre, and 23.6 b.h.p. per litre.

The weight of the engine is 960lbs., but as this does not include piping, etc., which is normally carried on British engines, the weight of the engine as installed can be taken as approximately 1,000lbs.

At 960lbs. the weight power ratio is 1.13lbs./b.h.p., and at 1,000lbs. 1.18; both figures being below that of the weight of the standard British engines which average 1.43lbs./b.h.p. at maximum r.p.m.

Under French type test conditions, engines are tested in a similar manner to that suggested for British engines under V.P. conditions. The engine is rated at a power at a given speed, in this case 2,400 r.p.m., and on no occasion is it tested under take-off conditions.

The boost pressure is maintained constant over the whole of the range, the only high speed test which the engine undergoes is one 10 per cent. in excess of the rated r.p.m. at a low power. The development of this engine must be looked upon as a remarkable achievement and it does indicate that a great deal can be done to reduce the weight of Service engines provided they are designed for a particular service.

The engine as it stands to-day is, practically speaking, the original 650 b.h.p. normally aspirated engine fitted with a supercharger. The six carburettors which were used on the original engine have been retained and are now coupled

to the supercharger by means of induction pipes carried on the air intakes of the carburettors and coupled to a supercharger mounted at the rear end of the engine.

The supercharger drive is considerably lighter than the present British types, as they do not use three slipping clutch wheels mounted round the impeller spindle, but rely on one clutch and wheel for the drive. I should estimate that this modification alone reduces the weight of the drive by 15/16lbs.

The supercharger is fitted with a light alloy impeller having the intake vanes bent over as is generally done in the American types. The impeller spindle is carried on two bearings in front of the supercharger rotor, thereby eliminating the tail bearing which is generally used in our type of supercharger. This has further reduced the weight by approximately 2lbs.

The boost control operates a throttle passing through the air intake to the supercharger.

The greatest saving in weight appears to have been effected by still adhering to two valves per cylinder. In practically every British engine we use four valves per cylinder which considerably increases the weight; owing to the additional complication by either the use of two camshafts per cylinder or by the use of rocker gear plus the extra valves.

The gas speed through the valves is considerably higher than we use in this country.

It would be impossible to obtain the m.e.p.'s at which we are at present running on engines using two valves per cylinder.

A further saving has been effected due to the engine being fitted with gas starting only, whereas we generally incorporate at least two and sometimes three methods of starting the engine which considerably increases the weight. The hand turning gear, for instance, adds approximately 10lbs. to most of our engines. We also provide extra drives for air compressors for operating the automatic pilot and also for charging the bottles for gas starting and other requirements.

No provision is made on the " Hispano " engines for these services. Provision is made for a generator drive. This is taken from an extra reduction gear wheel bolted to the main reduction gear shaft with the generator spigot mounted into the reduction gear casing. No slipping clutch is provided, whereas in our case we always provide this safeguard.

The reduction gear itself is exceptionally light.

The airscrew is arranged to bolt direct on to a flange on the airscrew shaft, which considerably reduces the weight of the reduction gear.

Weight Reduction

The weight of British engines could be reduced considerably if magnesium could be used as a general material for crankcases, etc. At present we produce engines for a universal purpose, which are extremely heavy for other services, and if it was decided to produce a service engine, taking into consideration all the methods of reducing the weight, it would be possible to produce an engine which would satisfactorily pass a 50 hours type test weighing 1lb./b.h.p. To enable this to be done, it would be necessary for all superfluous auxiliaries to be removed and for only one type of starting to be employed.

In cases where engines are intended for installation in the heavier types of aircraft and seaplanes, there would be no need to use magnesium castings; it is thought that a further improvement in reliability would be gained if the type test was extended to cover, in addition to the 100 hours bench test, a 50 hours flight test.

Supercharging

At present most of the advances which have been made in developing higher powers have been achieved by the use of superchargers. In nearly every case

mechanically driven centrifugal superchargers are used. The design of the impellers varies a little, but generally speaking is of a standardised type. Investigations into positively driven superchargers indicate that they are more efficient than the centrifugal type, but have not been adopted due to their excessive weight and the difficulty in building them into the engine in a satisfactory manner.

I think that the centrifugal type will remain with us for some time, but that considerable improvements will be made in connection with the method of driving.

At present it is the general practice to fit the carburettor before the supercharger. This has the advantage that it reduces the fire risk and reduces the number of component parts fitted to the engine as the carburettor is generally fitted with two chokes only, whereas with the carburettor after the supercharger, it is found necessary to fit at least one carburettor for two cylinders, the alternative being to fit two double choke carburettors in the " Vee " using the normally aspirated type of induction pipe directly coupled to a main air intake leading from the supercharger casing. Unfortunately, it is not possible to combine the good points of both systems into a common scheme.

Putting the carburettor before the supercharger leads to trouble in cold weather, as there is a tendency for liquid fuel to build up in the supercharger volute under slow running conditions, with the result that there is a danger of the engine cutting out during take-off unless adequate provision is made in the design to prevent the building up. This particular point requires further attention, as I am certain that under prevailing conditions, existing superchargers are not good enough in this respect, and that by further development, it might be possible definitely to overcome this disadvantage.

The distribution is generally good, but cannot be considered perfect. In liquid-cooled engines there is a tendency for the front cylinders to build up on occasions where the engines are opened up rapidly without having had sufficient ground running.

In the case of the engine fitted with carburettors after the supercharger, there is no trouble with fuel building up in the supercharger casing, and in addition, the distribution can be adjusted by the use of multiple carburettors. Unfortunately, this system can be set up satisfactorily on the test bench, but when installed in an aircraft, the conditions alter, due to air intake, etc., and it is generally found necessary to retune the carburettors. Further, when the carburettors are tuned, it is practically difficult to keep them adjusted for any length of time, due to the alteration which takes place in the link gear coupling the carburettors together.

The carburettors have to be pressure fed and it is essential for the throttle glands to be packed to withstand the pressure. As the carburettors are generally located near the exhaust pipes, and as there are a number of pipes leading to the various carburettors, in the event of any of the pipes breaking or the glands leaking, the fire risk is great.

It is probable that multi-speed superchargers will be used in conjunction with the mechanically driven centrifugal type. Advantage is gained by using the low speed stage of the drive for take-off, as it has been found possible to use a higher boost under these conditions.

Difficulty is experienced in producing slipping clutches which will satisfactorily operate over the range.

Exhaust driven superchargers should be re-considered, particularly for high altitude aircraft, as previous experiments carried out on this type of supercharger have proved successful.

Inter-coolers were used for the previous experiments; these were necessary, due to the close proximity of the exhaust driven turbine to the supercharger impeller.

In my opinion, if the driving turbine had been isolated from the supercharger rotor, it would not be necessary for inter-coolers to be used.

Fuel Injection (Petrol)

The introduction of fuel injection should overcome both difficulties, *i.e.*, building up and fire risk, as it will be possible for the atomisers, particularly in the case of " V " engines, to be inserted inside the cylinder blocks in such a position that a fuel pipe breakage will not allow fuel to be sprayed on to the exhaust pipes, the building up, of course, being eliminated by the fact that the supercharger would only be delivering air.

In connection with fuel injection, a great deal of experimental work is being undertaken, with a view to proving out the scheme. In some cases good results have been obtained, but it is impossible for the time being to give a definite indication as to what will be the ultimate result of the experiments. I think that we shall gain a great deal by using the fuel injection scheme, as it is possible to produce a fuel pump which will definitely measure the quantity of fuel being delivered to each particular cylinder, and at the same time making it possible for

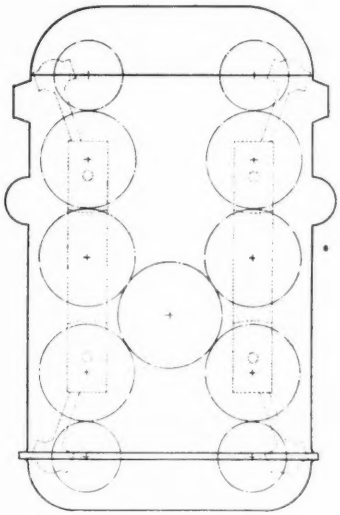

FIG. 21.

Double " Jumo IV."

the fuel to be injected at the correct time into the cylinder. Further, it will be possible to deliver to the engine the correct fuel air mixture to give complete combustion.

In U.S.A. they are testing out two schemes; one injecting the fuel directly into the cylinder, as is generally done in the case of " Diesel " engines, and alternatively, by injecting into the induction pipe.

It is probable that the latter scheme will prove to be the best as it is possible that it will reduce the number of atomisers and also the weight of the fuel pumps.

A further advantage of using the fuel injection scheme will be that freezing troubles which existed at altitude on engines fitted with carburettors will be practically eliminated.

Compression-ignition Engines

Various types of compression ignition engines are undergoing development, the chief one being the Junkers " Jumo." This is a two-stroke fitted with

opposed pistons, the pistons being coupled to two crankshafts located at the extreme ends of the crankcase, the crankshafts being coupled together by gearing; one of the intermediate wheels being used to drive the airscrew shaft. A centrifugal supercharger is used to deliver the air to the cylinders.

Fig. 11 shows the relative size of this engine compared with a petrol engine developing the same power. It will be seen that the petrol engine has a low frontal area compared with that of the compression ignition engine, and it also has the advantage that the weight is 960lbs. compared with the " Jumo " weight of 1,775lbs. As already stated, the compression ignition engine will be useful for long range commercial aircraft as low fuel consumption definitely rules out the engine weight when the range is over $7\frac{1}{2}$ hours.

This engine has been type tested and fuel consumption readings as low as 0.35lbs./b.h.p. have been obtained. This is lower than we can hope to get from a petrol engine.

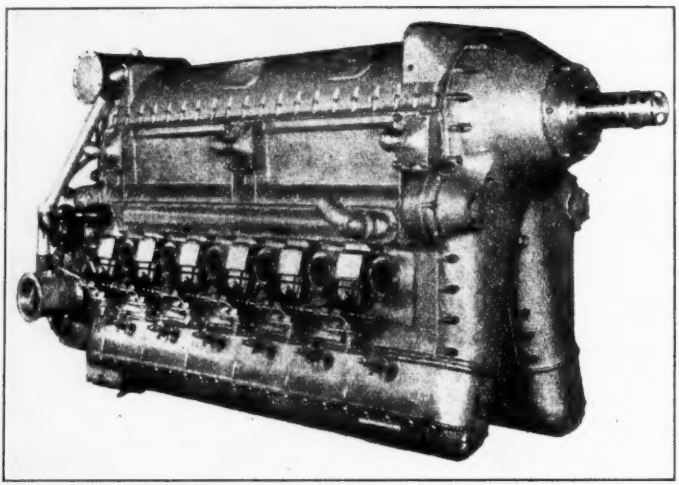

FIG. 22.
Deschamps Diesel Engine.

Fig. 21 shows a further development which may take place. This covers coupling two " Jumo " engines together into a common crankcase, thereby making it possible for a 1,500 h.p. engine to be produced without increasing the height of the engine, and at the same time producing one which could be installed in a small space. The advantage of this type in large aircraft is that it would be possible for the pistons to be extracted when necessary without removing the engine from the air frame, and at the same time producing a high powered engine with a reasonable frontal area.

A 1,200 b.h.p. " V " liquid-cooled engine is being produced in the States. This is also of the two-stroke variety, the weight power ratio is given as 2lbs./b.h.p., but it is very doubtful if this will be possible as the general construction of the engine examined so far indicates that a great deal of stiffening up will have to take place before the engine will be a success. Fig. 22 shows a photograph of the proposed engine.

Two-stroke Engines

Many attempts have been made to produce a satisfactory two-stroke engine. So far nothing has come up to the standard of the present four-stroke, and I am inclined to agree with Mr. Fedden that the only prospect of producing a satisfactory two-stroke engine is to have it supercharged, using fuel injection.

The orthodox port type is most inefficient and from investigations I have made from time to time, it will be absolutely essential to use valves, and as these have to operate at high speeds, it will be necessary for the valves to open and shut alternately in the cylinder head, *i.e.*, half engine speed—two inlet and two exhaust. This immediately restricts the b.h.p. which can be developed out of the cylinder, as the four valves which could be fitted into the head would be the same area as those usually fitted to a four-stroke engine.

As already pointed out, difficulty is experienced in obtaining sufficient valve area in the four-stroke cylinder heads using two valves. Therefore it will be most unlikely that an efficient cylinder could be produced by using four valves operating at half engine speed.

Regarding the fuel injection side, there is a limitation to the pump speed, and as these would have to operate at engine speed, it might mean that double the number of pumps would have to be used for the two-stroke engine. The result would be a complicated piece of mechanism which would probably develop approximately the same b.h.p. per cylinder as that now obtained from the present four-stroke.

It is possible, however, that the sleeve valve engine may be made to work satisfactorily on the two-stroke principle. Mr. Ricardo has already obtained satisfactory results from a cylinder of this type. If the sleeve valve side is satisfactory, it might be possible to overcome the difficulties with the fuel pumps.

Sleeve Valve Engines

Various sleeve valve liquid-cooled engines have been produced in this country; mostly single sleeve type. The results obtained from an efficiency point of view have been most encouraging, but the weight power ratio has been extremely high. It is possible to carry one compression ratio higher in the cylinders than is generally used with poppet valve engines. The fuel consumption is very good. Troubles were experienced with junk rings, but it is possible that due to the result of the experiments carried out by Mr. Fedden that this definitely has been overcome.

The main objection to the sleeve valve engine is the danger of a breakage, particularly in the sleeve valve mechanism. This failure does a great deal of damage to the engine.

In the ordinary way, if a valve spring or a valve breaks, it is general for the engine to carry on. In the case of a sleeve breakage, the consequences are mostly serious with the result that the engine stops. A further objection to the sleeve valve engine is difficulty in starting in cold weather. It was found exceptionally difficult to start the engines in mid-winter, due to the congealed oil on the sleeves and cylinder walls preventing the engine from being readily turned.

Gas Turbines

One gas turbine per day is invented the whole year round. So far nothing has been produced which has indicated success. The general principle adopted is to provide a rotating vane pump with some form of mechanism for compressing the gas and exploding it by means of sparking plugs on the periphery of the casing.

I hope that some time in the near future a satisfactory turbine will be developed, as this would entirely revolutionise our ideas of aircraft propulsion.

Steam Engines

One or two aircraft have been produced lately with steam installations.

Investigations were carried out on this system some years ago, using a flash boiler in conjunction with small steam engines. No difficulty was found in producing satisfactory engines, but the boiler, water, condensers, etc., were too heavy to afford further consideration.

Combined Air- and Liquid-cooled Engines

It has been suggested from time to time that an advantage would be gained by using a cylinder construction consisting of a liquid-cooled head fitted with air-cooled cylinder barrels. At first sight this appears to be attractive, but from a design standpoint, there is considerable difficulty in producing a satisfactory assembly of the barrels to the head.

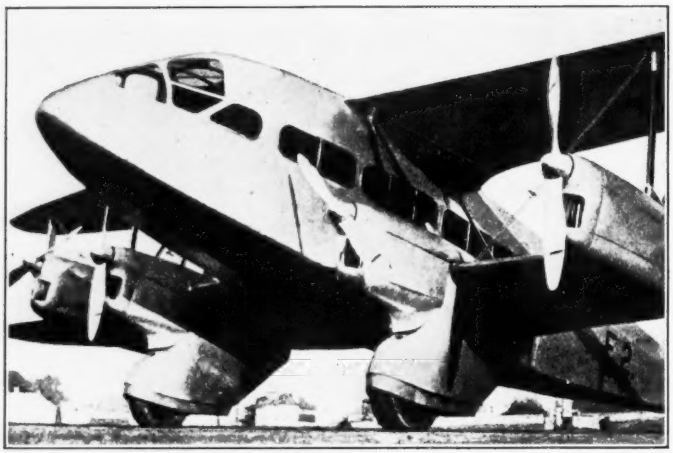

FIG. 23.
De Havilland "Dragon."

The cylinder head has to be cooled low enough to cover the complete combustion space which necessitates a deep section, with the result that the portion of the barrel which could be air-cooled comes out too short to be of any advantage.

As the chief feature of the liquid-cooled engine is that it can be totally enclosed in the cowling, the introduction of the finned cylinder barrels would necessitate breaking down the clean lines to allow the air to enter the cowling to cool the cylinder barrels.

Swash-plate Engines

It is most unlikely that this type of engine will be produced for aircraft services, as the weight power ratio of engines already designed have come out much higher than that obtained from the normal type of engine.

Air-cooled In-line Engines

The small air-cooled in-line engine instals most satisfactorily into an engine nacelle, Figs. 23-24. No trouble is experienced in cooling the rear cylinders, and it is possible that this type of engine will have a great field in low powered

commercial aircraft. In some cases larger size engines have been produced, such as the " Isotta-Fraschini " 60° " V " engine. Difficulty was experienced in this case in cooling the rear cylinders. I believe the firm have dropped it in favour of the 60° " V " liquid-cooled type. The 60° " V " in-line air-cooled engine is attractive, but it has the same disadvantage as other air-cooled types, that it is impossible to instal the engine in a clean cowling.

The only prospect of producing a satisfactory in-line air-cooled engine would be to introduce some form of forced cooling, as was suggested by Mr. Fedden. This would enable the complete installation to be totally cowled in and would at the same time eliminate the drag of the radiator which is at present used on the liquid-cooled type. It is most unlikely, however, that the results obtained from this combination would be better than the suggested installation using a liquid-cooled " V " engine in conjunction with glycol cooling.

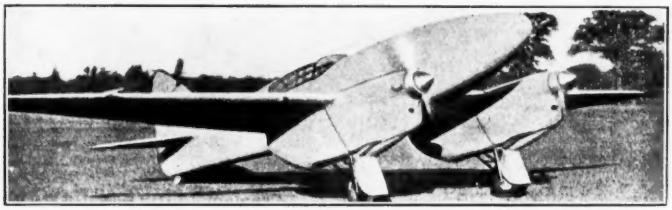

FIG. 24.
De Havilland " Comet."

Starting Gears

As previously stated, if engine weights are to be reduced, it will be necessary to standardise one type of starting. At present we have:—

(*a*) *R.A.E. Mark II Type*, which necessitates the use of a distributor, non-return valves, air bottles, and to complete the system an engine driven air compressor. The all-up weight of this apparatus is approximately 33½lbs.

(*b*) *Cartridge Starting.*—This is extremely light, but has the disadvantage that it is necessary to carry cartridges in the aircraft and definitely to turn the engine to put one of the cylinders on compression. In single-engined machines, this scheme has been found satisfactory, but in multi-engined aircraft, where the engines are inaccessible, this system would not be satisfactory for Service use.

(*c*) *Inertia Starters—Hand-Operated.*—The component weighs 28lbs., and when fitted to an aircraft it is generally found necessary to add chains or shafting to enable the gear to be turned from the ground. As a rule, the installed weight of the apparatus is 35lbs. The disadvantage of this type of starting is that it is exceptionally difficult to energise the fly-wheel, particularly in cold weather. Further, when the starting dog is engaged into the end of the crankshaft, the rear end of the engine is subjected to very high stresses, and in some cases additional stiffening up to the extent of three or four lbs. has to be added to cope with this condition.

The electrically energised fly-wheel type is extremely heavy (unit 35lbs.), and in addition, the current used by the motor is too high to allow a service battery to be used continuously.

(*d*) *Electric Starting.*—This covers the use of a small electric motor running at high speed (6,000 r.p.m.) coupled to an ordinary hand-turning gear through gearing which enables the engine to be turned at approximately 9 r.p.m. The current required for this motor is exceptionally low. The all-up weight of the apparatus increases the weight of the engine in addition to the hand turning gear by approximately $7\frac{1}{2}$lbs.

FIG. 25.
Electric starting turning gear.

Fig. 25 shows this type of starting fitted to an engine. The advantage of using this type when properly designed is that, in addition to the electric starting, the mechanism can be so arranged that the engine can be hand-started in the event of an electrical breakdown.

From tests that I have carried out, this appears to be the best type to adopt as standard, as the engine is definitely turned for starting purposes, thereby eliminating the danger which is common to gas starting systems due to leaky valves, allowing the mixture to escape.

Cowling

The cowling of liquid-cooled engines should receive careful attention as it is essential that the engine should be wholly cowled in. In many cases it is common practice to add small additional covers to enclose the front ends of the cam case covers or the jacking points.

To obtain maximum efficiency, the cowling should be designed to give a clean contour and the practice of adding pieces to the cowling should be discontinued.

In some cases it is found necessary to provide additional cooling for the crankcase. The general practice is to cut a hole through the cowling, thereby reducing the efficiency. It has been found possible to provide crankcase cooling by coupling the air intake to a double skin on the sump, thereby eliminating any necessity for holes having to be cut in the cowling.

Flush fittings must be used to fasten the cowling. The introduction of skewers definitely affects the cowling efficiency.

The foregoing briefly gives my views on possible developments and improvements which I hope in some small way will assist in improving our aircraft.

I wish to thank the British Air Ministry, the Fairey Aviation Co., Ltd., and other contractors for their permission to make use of certain data and to exhibit slides of their products.

Discussion

The Chairman: The rival merits of air-cooled and water-cooled engines had been discussed for many years, and it was of some interest to note that the Schneider Trophy races of 1927, 1929 and 1931 had all been won with water-cooled engines. Possibly as the result of that there had been, about 1930, a swing of opinion in favour of the liquid-cooled engine. In 1934, however, there had been the England-Australia race in which it might be said the air-cooled engine had swept the earth. He felt, however, it would be just as much a mistake to assume on that ground that the liquid-cooled engine was dead, as it was in the earlier days to think that the air-cooled engine would recede in importance. They were, therefore, most grateful to Captain Forsyth for coming and counteracting any tendency to over-enthusiasm towards air-cooling. At the same time, Captain Forsyth was a generous protagonist of the liquid-cooled engine, because in his paper it was stated that the " Dagger " engine, which was air-cooled, gave 41 b.h.p. per litre, and that this output was much higher than had been obtained from any other type of aero engine, apart from racing engines. He drew attention to this, added the Chairman, because it concerned one of two general points he wished to put forward. The author had spoken in many places about b.h.p. per litre, but he, the Chairman, wished to sound a note of warning because, although a figure for the b.h.p. per litre was quite a good way of comparing the merits of engines of the same cylinder size, it was totally misleading as a standard of comparison of the merits of engines with cylinders of different sizes. Calculation showed that two engines, geometrically similar, of the same merit as regards thermal efficiency and volumetric efficiency, would have a b.h.p. per litre inversely proportional to the linear dimensions of their cylinders. For instance, in the case of two engines, one having a bore of 4 inches and the other a bore of 6 inches, if the former did not have a b.h.p. per litre 50 per cent. better than that of the latter, then it was a less efficient engine. It was important to bear that general point in mind when one was speaking of b.h.p. per litre as if it were a universal standard of merit.

The other general point he wished to make, continued the Chairman, was in regard to frontal area. Several diagrams had been shown to illustrate how much less was the projected frontal area occupied by a liquid-cooled engine than by an air-cooled radial. It was dangerous, however, to lay too much stress on frontal area. Professor Jones, of Cambridge, had once pointed out that the air resistance of a sixpenny piece placed across a wind-stream was about equal to that of a streamlined body as big as a fair sized pear. That brought home to one that frontal area was not a thing about which one could argue without taking into account the form of the body behind the frontal area.

However, as Chairman of the meeting, he was not going to take one side or the other. He felt that the right way to deal with a paper of this nature was not to make speeches about it, but to ask questions; and for the author to reply at once. Dealing with the paper in that way, therefore, he wished to ask three questions. The first was with regard to ethylene glycol cooling, about which a good deal had been said in the paper, and it was undoubtedly a very interesting development. Could the author give the results of his experience in connection with any difficulties which had been experienced when using glycol with an engine designed for water-cooling?

The second question related to the statement which read:—" Racing engines have to pass a test of one hour's duration at full throttle and if developed to run at two-thirds power would pass a 50 hours type test." That was rather a sweeping statement. His recollection was that the Schneider Trophy engines, which had to pass a one hour's type test at full throttle, gave 2,400 b.h.p. and on the 100 hours' type test practically the same engines gave 825 b.h.p. Did the author consider that these engines would have survived a 50 hours' test at 1,600 b.h.p.?

The third question he had to put related to the sentence:—" It would be impossible to obtain the m.e.p.'s at which we are at present running on engines using two valves per cylinder." Would the author expand that a little, for he believed it was true that American practice was almost universally developed on two valves per cylinder. Was it not a question of valve size rather than valve number?

Reply to Mr. Pye.—He agreed with the Chairman that it was misleading to quote the b.h.p. per litre. The reason for doing so was to bring this paper into line with the previous one given on air-cooled engines.

Regarding frontal area, the example quoted of a sixpenny piece placed across a windstream as compared to a streamlined body as big as a fair sized pear did show the advantages of streamlining. He contended, however, that the area of a radial air-cooled engine should be taken as approximately the same size as half-a-crown, and that the sixpence would represent the liquid-cooled engine. It will therefore be appreciated that if the sixpence is properly streamlined, it will have a much lower head resistance than that of the streamlined half-a-crown.

The chief difficulties encountered in producing satisfactory ethylene glycol cooling systems is to produce piping and joints which will prevent leakage as the liquid is more searching than water, with the result that radiators and joints which are satisfactory with water are unsatisfactory with glycol. Experiments have proved that provided joints are made of special design, they will stand up equally as well as the joints previously used in water-cooled systems.

Regarding the modifications which are normally required to the engine, the running clearances have to be increased to approximately those of the air-cooled type.

With regard to running a racing engine at two-thirds power, he naturally meant that the r.p.m. would be brought down a reasonable amount. Racing engines were normally run at 3,200 r.p.m. and taking 20 per cent. below, it would mean that the " R " engine would develop about 1,200 b.h.p. at 2,000 r.p.m.

He agreed with the Chairman that it was the general practice in America to use two valves per cylinder on large air-cooled radial engines. In the case of the liquid-cooled engine, considerable difficulty is experienced in using two valves large enough to give the required area without unduly increasing the dimensions of the cylinder head castings and the weight of the engine. It would be quite possible to produce a liquid-cooled engine with two valves per cylinder, but the introduction of this method would considerably increase the frontal area and would, to a certain extent, reduce the advantages which are at present gained by the small frontal area which can be obtained by using four valves per cylinder.

In the paper it is pointed out that development of the Hispano-Suiza engine would, to a certain extent, be limited, due to the fact that it is impossible to increase further the dimensions of the valves.

Mr. W. O. MANNING (Fellow and Member of Council): Was it really necessary that some of the useful energy developed by the propeller should be used in cooling the engine? That point might be illustrated by a reference to the Lewis machine gun which might be considered, without grave error, as a special type of internal combustion engine, developing some 50 h.p. for a weight of 20 to 25lbs. The conditions as regards efficiency, etc., were very much the same as in the case of a petrol engine. The thermal efficiency was about 25 per cent. and the amount of energy wasted in the jacket and in the exhaust was very similar, roughly speaking, to that of a petrol engine. It might, therefore, be said that when the gun was working at its maximum output the amount of heat to be got rid of was comparable with that in one cylinder of an air-cooled engine developing, say, 50 h.p. per cylinder. The barrel of the gun was surrounded with a cover containing a number of fins and the air was ejected through the fins by means of the actual exhaust at the muzzle of the gun. In other words, the energy used for producing the cooling draught round the barrel was not taken out of the useful energy of the gun, but out of the waste energy, *i.e.*, the kinetic energy which would otherwise be wasted in the exhaust gas. Therefore, it would seem, that some such method might be adopted with the aero engine.

Continuing, Mr. Manning put two other questions. The first was whether in comparing the frontal area of the two types of engine did the author include the frontal area of the radiator in the case of the water-cooled engine?

His second point was that the author had shown a horizontal engine fitted in a wing, but that seemed to him to introduce certain difficulties especially with regard to the front spar.

Reply to Mr. W. O. Manning.—On the first point as to the cooling of an engine, this matter has been gone into and, although working on the lines suggested by Mr. Manning, has proved successful with engines of reasonable power, it was not so in the case of really high efficiency engines. Franklin had used finned cylinders with a fan blowing air through them and Irvine had used a modification to the Franklin arrangement by introducing Venturi cowlings over the exhaust stub pipes with the object of further improving the circulation of air through the cylinder casings.

Regarding the frontal area, in all cases where figures were quoted for liquid-cooled engines the radiator area was included.

Finally, with regard to the horizontal engine in the wing, the illustration shown was in diagram form, but it was found possible to produce a design of a wing with a satisfactory front spar.

The chair was then taken by Major T. M. BARLOW, Member of Council, who said he would like to make a correction in the speed of the consolidated machine which had been shown by the author. It should be 258 miles per hour and, incidentally, that was with the supercharger. It was hoped to get 270 miles an hour with the internal engine-driven supercharger.

With regard to Mr. Pye's reference to the comparison of merits of engines, as an aircraft engineer he felt that engines should be compared as power units and not on the basis of test-bed ratings of so much per litre and so on. He would consider the comparative features under three headings: (1) weight efficiency, *i.e.*, the weight efficiency of the power unit as a whole, including airscrew, cowling, manifolds, mountings, tankage, petrol, etc., all of which were affected by engine design; (2) aero-dynamic efficiency, which would depend on the cowling and the drag of exhaust manifolds which had to be fitted, air intakes, oil coolers, etc.; and (3) maintenance, ease of mounting, access, etc. There was little doubt in his mind that the reason why the efficiency of air-cooled engines had increased during the last year or two was because consideration had been

given to these three items, and the results had been apparent in the London-Melbourne race as well as in American civil aviation. Therefore he stressed the point that if engine rating was only considered based solely on h.p., size, etc., it was impossible to arrive at the real value of the engine to the aircraft. It was impossible to divorce the engine unit entirely from the aircraft in comparing their relative merits.

Reply to Major Barlow.—In putting forward the advantages of the liquid-cooled engines, under the first heading it would appear that the liquid-cooled engine scores considerably over the air-cooled type.

The liquid-cooled engine also has another advantage.

The present-day air-cooled motor has lost most of its advantages due to its complication.

The present-day liquid-cooled motor is not so difficult to maintain as the latest air-cooled types. It must be admitted, however, that both types have become more complicated and more difficult to maintain due to the introduction of superchargers, etc.

Mr. W. P. SAVAGE (Associate Fellow): Did the author consider the in-line air-cooled engine when making out his case for the liquid-cooled engine? What was, in the opinion of the author, the limit of m.e.p. to be obtained from a two-valve air-cooled cylinder?

Reply to Mr. W. P. Savage.—He had already said that it was generally agreed that the in-line air-cooled engine is very satisfactory in small sizes, but he felt that there were limitations to the size in which the in-line air-cooled engine could be built. His own view was that the limit would be found to be a $4\frac{1}{2}$in. or 5in. bore cylinder.

He further agreed that the small in-line air-cooled engine was very efficient and would not be easily beaten by a small liquid-cooled engine.

The m.e.p. which could be obtained from a two-valve cylinder, he believed, was, according to tests in America, 248.

Captain A. SWAN (Associate Fellow): Like Mr. Pye, he was neutral in this healthy competition between the air- and the liquid-cooled engines. He admired the illustrations in the paper showing the benefits of liquid-cooled engines, and would very much like to see a similar set of illustrations drawn by the air-cooled engine protagonists from their point of view. Although in favour of ethylene glycol cooling he felt that the author was a little optimistic when he said that the radiator would be one-third the size with a cooling temperature of 130°C. He had calculated that with that temperature the radiator size would be about 60 per cent. of the water-cooled radiator. When ethylene glycol was considered originally, a cooling temperature of 150°C. was contemplated and then it was reckoned that the radiator would be rather less than one-half the water radiator. Therefore he would like a little evidence on what the author said regarding this matter.

It was stated that the engine speed of the air-cooled radial engine was limited as compared with the water-cooled engine, but presumably the author there was thinking of bearing loads in cases where there were many cylinders concentrated on one crank. The piston speed was really more important than rotational speed. He had looked up some figures and found that a single throw radial engine in this country has a higher piston speed than any other type of aero engine; possibly the author was basing his comparison on racing engines which, of course, were very special.

Again it was stated that the liquid-cooled engine scores when the duration is over five hours. It would be interesting to know how that was; it implied a much lower consumption than in the case of the air-cooled engine. It was probably true that the liquid-cooled engine had a slightly lower consumption, but it would require to be very much lower to give advantage in the short time of five hours.

Mention had been made by Mr. Pye of the question of h.p. per litre, and he himself had raised that some time ago. It could be illustrated by a very simple example. If one took a cylinder of a certain size and halved its bore and stroke, it was possible to double its rotational speed and keep the piston speed the same, which was quite legitimate. Yet that small engine compared with the larger engine should give twice the h.p. per litre, otherwise it was a bad engine. That type of comparison was sometimes made between small-sized racing car engines and aero engines to the apparent disadvantage of the latter. He was in agreement with Major Barlow that the criteria which should be used in the case of the aero engine, speaking entirely from the point of view of considering the engine only, was the weight per h.p. developed and the drag imposed by the engine.

Reply to Captain Swan.—The calculations of radiator sizes which had been criticised were actually based on an aircraft which is flying in this country at the present time, of the high-speed type. He agreed with what had been said with regard to calculating b.h.p. per litre, but the reason he had quoted the figures given in the paper was because it was a direct reply to a paper by Mr. Fedden last year in which the b.h.p. was quoted per litre. At the same time, he agreed that it was the wrong way to state the case, but had replied in the manner he had to complete the story for the reasons stated.

Regarding speeds, he was only referring to rotational speeds, and he agreed that the piston speeds were just as high with the air-cooled engine as with the liquid-cooled engine. At the same time he felt that the liquid-cooled engine had the advantage that it would be possible to get to much higher piston speeds than would be possible in the radial engine.

He saw no reason why a 6in. stroke engine should not be run at 3,500/4,000 r.p.m. continuously, and under these circumstances the piston speed would be much higher than one would hope to run the air-cooled type.

It is true that the figures for fuel consumption for two types of engines did not agree. The position was that the figures given for the air-cooled engine of 0.5 or 0.51 were test-bench figures, and under actual flight conditions they were generally something of the order of 0.62 or 0.63.

The liquid-cooled engine suffered in the same way. Test-bench figures were generally quoted as 0.48 cruising, but in practice they were more likely to be 0.51, so that the liquid-cooled engine was really a little better than the air-cooled engine from a consumption point of view.

The five hours' duration was based on actual figures taken from two identical aircraft, in the one case the engine being air-cooled and in the second case with a liquid-cooled engine installed.

Regarding the illustrations, if the protagonists of the air-cooled engine were to produce similar illustrations, they would be identical with those shown, as the dimensions were based on actual installations taking into consideration the latest liquid-cooled practice.

Mr. A. Clinton (Associate Fellow): The Chairman had admirably summed up aero engine requirements under three headings, but he would like to add a fourth, viz., comfort and confidence. In the case of commercial aircraft, it had been demonstrated that both confidence and comfort were obtainable to a high degree.

In the case of military aircraft, there was naturally not such a high degree of general comfort, and one item affecting comfort, viz., noise, needed more attention that it was at present receiving. Apart from increased comfort, the absence of noise was of great tactical value. With military machines, the question of confidence was largely influenced by vulnerability; this had only been lightly touched upon in the paper.

The aim in the training of any personnel in the Services, was that in time of emergency and under the worst of conditions a man should maintain a moral

ascendency over his opponent, as it was only in that way that it became possible for one side to impose its will on the other. To accomplish this, the individual —or the crew of the aircraft—had to have the utmost confidence in the fighting equipment, and anything tending to increase vulnerability, and hence reduce the confidence of the crew, had to be avoided if at all possible. It was submitted that for an air-cooled engine installation the following factors would tend to increase the confidence of a crew:—

(1) Use of sleeve valve engines, thus obviating poppet valves and their necessary operating mechanism.
(2) Fitting of large volume exhaust collectors.
(3) A self-contained installation, free from accessory cooling devices.

On the question of heating cabins, and other parts of the machine, the use of glycol seemed to involve certain problems in plumbing, whereas by using hot air from exhaust collectors easier maintenance was possible.

Reply to Mr. A. Clinton.—He agreed with Mr. Clinton's remarks in connection with producing aircraft with a high degree of comfort and absence from noise. In his opinion, the liquid-cooled motor was much quieter in operation than the air-cooled types, due to the silencing effect of the liquid surrounding the cylinder blocks, etc.

Sleeve valve engines are referred to in the context of the lecture.

Regarding silencers, there were various opinions in connection with fitting efficient exhaust silencers, and the author thought that the final opinion was that when efficient silencers were fitted it was difficult to eliminate the airscrew noise and also the screeching which comes from the flying wires, with the result that an aircraft with silencers fitted is more easily spotted than an aircraft fitted with normal manifolds.

On the question of heating cabins, he thought that it would be preferable to use some form of heating which definitely eliminated the possibility of carbon monoxide entering the cabins, thereby causing discomfort to the pilot and the crew.

Lieut.-Colonel L. F. R. Fell (Fellow) (*communicated*): Throughout his remarks on head resistance, Captain Forsyth compared the water-cooled "V" engine with the nine-cylinder single row radial instead of with the 14-cylinder double row radial. While it was readily admitted that the nine-cylinder single row radial engine had special advantages not possessed by other types, small diameter was not one of these advantages. Actually it seemed reasonable to suggest that the drag of the 14-cylinder radial engine installed with modern cowling would be considerably less than the drag of the water-cooled engine installed complete with radiator.

It was claimed that the water-cooled engine "can be fitted with reduction gears enabling the airscrew shaft to be located in the best possible position relative to the engine shaft, thereby producing the best cowling lines." Surely there could be no better position for the airscrew shaft than that which it occupied on the majority of air-cooled radials. If it were desirable to raise the airscrew shaft, this could, of course, easily be done by the use of spur gears as employed on the Pobjoy engine.

It is thought that to-day, with improved bearings both as regards design and materials, engine speed is limited only by valve operation. This limitation applied equally to the water- and air-cooled engines.

It was stated that liquid-cooled engines were generally lighter than radial air-cooled types developing the same power. He submitted that this statement is not to-day supported by the facts, especially if the weight of the water installation is taken into account.

In the comparison sketch the diagram on the right-hand side of the page does not correspond with that on the left, as the obstructions at the rear of the water-cooled engine both on the sides and at the bottom are not drawn in,

thus making the comparison appear very much better for the water-cooled engine than it really is.

Under the heading of "Increase in power," the author referred to the improvement which had been made on the liquid-cooled engine performance by increase in engine speed, increase in boost pressure and by the introduction of 87 octane fuel. With regard to the increase in speed, the limitation to further increases was the same for both the air- and water-cooled engine. The introduction of 87 octane fuel had, however, benefited the air-cooled engine to a considerably greater extent than it had improved the liquid-cooled, as the importance of suppressing detonation to the air-cooled engine was far more vital than it was to the water-cooled engine. It was a fact that the introduction of 87 octane fuel had done more than anything else in recent years to reduce the advantages which the water-cooled engine held over the air-cooled engine in the past. For it was possible now to use on air-cooled engines compression ratios which under cruising conditions gave fuel consumptions practically equal to those obtainable from the water-cooled engine; higher boost was also permissible without overheating.

As was pointed out by Mr. Pye, it was only accurate to compare engines on a basis of h.p. per litre if they were of similar bore and stroke.

With regard to the comparison of British with Continental engines, the method of rating of British engines differed from that of either the Continental or American. The Continental and American methods were really more correct, as the British rating figures were not in fact related to any actual condition of running the engine in flight.

On the Continent, and in America, the maximum power was given at maximum r.p.m., whether on the ground or at altitude. This was the figure on which the aircraft constructors based their calculations both in this country as well as abroad. The so-called normal power at normal speed quoted in this country was really of no assistance to an aircraft constructor in comparing the performance of one engine with another. It was thought that if the Continental engines referred to were compared with British engines in the light of these remarks, it would be found that there would be little to choose so far as output was concerned.

It was thought that the greatest hope for the future of the water-cooled engine lay in the satisfactory development of dragless cooling; when this could be achieved without introducing undue complication, and consequent instability and unreliability, the water-cooled engine would be able to claim an advantage in respect of drag which it was difficult to see could ever be entirely equalled with any form of air-cooled engine.

Reply to Lieut.-Colonel L. F. R. Fell.—He did not agree with the suggestion that the 14-cylinder radial engine installed in modern cowling would have less drag than a properly installed liquid-cooled motor using ethylene glycol as a coolant, as it has already been pointed out that it is possible to totally house the liquid-cooled motor into a properly streamlined nose and that the only remaining drag is that of the radiator required for the installation.

Raising the airscrew shaft position of a radial engine does not improve the cowling line of the aircraft, but has the effect of giving the airscrew a higher ground clearance.

The liquid-cooled engine with four valves per cylinder scores over the radial engine fitted with two valves, as it is possible to operate the valve mechanism at higher rotational speeds.

Taking the liquid-cooled installation as a whole, including radiator, coolant, etc., and in addition the saving in fuel consumption, the weight of the complete aircraft is practically the same as that of an aircraft with an air-cooled engine installed. A typical example is where two identical machines were fitted with air-cooled and liquid-cooled engines, where it was found that the all-up weight

of the liquid-cooled machines was 56lbs. lighter than that of the air-cooled installation. Further, the range of the liquid-cooled aircraft was greater, and also the maximum speed was higher.

In preparing the diagrams showing the frontal area of the water-cooled and air-cooled engine, the rear end of the liquid-cooled engine was not drawn in, due to the fact that the areas were taken at the same point from the nose of the engine as installed.

It will readily be seen that in the water-cooled engine the outline of the engine closely follows the contour of the cowling, and the introduction of the water pump, etc., at the rear end does not in any way alter the cowling outline.

Regarding the use of 87 octane fuel, he agreed that the introduction of this fuel benefited the air-cooled engine, but it also has had the effect on the liquid-cooled engine in so far that it is possible to still further raise the compression ratio and, due to the higher rotational speed which is possible on the liquid-cooled engine, detonation is suppressed by the use of this fuel and also a substantial gain in power.

Regarding the rating of engines, he was also in favour of engines being type-tested under conditions which would compare favourably with flight conditions.

Mr. C. F. TAYLOR (*communicated*): In his discussion of numerous details, Captain Forsyth failed to emphasise the two most important considerations in the question of liquid cooling, versus air cooling for aircraft engines.

The primary advantage of the air-cooled engine lay in the mechanical simplicity of the installation as a whole, with its absence of the radiators, piping, connections, pump and jackets characteristic of the liquid-cooled power plant. The importance of that simplification, together with the reduction of first cost and of maintenance cost, freedom from boiling, freezing and leakage, would offset a considerable performance advantage for many types of aircraft. That this was true was attested by the wide use of air-cooled engines, even though there are many highly developed liquid-cooled types available.

But it seemed the item of paramount importance was the fact that cooling was the factor which limited engine output per unit of displacement, in the case of the air-cooled engine. If improvement in cooling did not keep pace with the demand for higher specific outputs, it was possible that liquid cooling would be again forced upon them. It was impossible to predict that with assurance, however, since the exact point at which considerations of high specific output would overbalance considerations of mechanical simplicity, low cost and easy maintenance could only be determined by wide service experience. Even in the military field, that balance was of great importance.

Captain Forsyth's statement that the performance of many present types of airplanes could be somewhat improved by the use of liquid-cooled engines was probably true. In this connection, however, two important points should be noted: (1) that the gain in performance would be noticeable at low angles of attack only. At high angles of attack, power-plant drag is such a small proportion to the total drag that the gain in performance, if any, would be negligible. (2) That even at low angles of attack, the possible gain in performance due to reduced power-plant drag is not very large.

He would like to take issue with Captain Forsyth on some detail claims he made for the liquid-cooled engine. First among these was the claim that fuel and oil economy were better. That was the case at maximum output only, the cruising economies of the two types being practically the same. Since the cruising economy controlled the amount of fuel and oil to be carried, the advantage of the liquid-cooled engine in economy at maximum output was of little practical value.

He also stated that the liquid-cooled power plant was lighter than the air-cooled power plant of equal output. This statement must have been based on

the well-known fallacy of weighing liquid-cooled engines without their cooling systems. Omitting special racing installations, the advantage in weight was certainly still on the side of the air-cooled power plant, as shown by Table I, attached.

TABLE I.

DATA ON SOME RECENT AIRCRAFT ENGINES (EXCLUDING RACING MODELS).

(Weight of Liquid-Cooled Types does *not* include cooling system.)

Engine.	Model.	Type (Cooling).	Maximum Published Performance. Alt. ft.	b.h.p.	r.p.m.	Weight, geared. lb.	lb./b.h.p.
Wright ...	Cyclone ...	9R. A.C.	3,900	735	1,950	1,015	1.38
Wright ...	Two-Row ...	14R. A.C.	0	700	2,300	870	1.24
P. & W. ...	Hornet ...	9R. A.C.	6,500	700	2,150	1,017	1.45
P. & W. ...	Twin Wasp...	14R. A.C.	7,000	800	2,400	1,162	1.45
P. & W. ...	Wasp... ...	9R. A.C.	8,000	550	2,200	875	1.59
Bristol ...	Pegasus III...	9R. A.C.	0	775	2,525	1,060	1.37
Rolls-Royce...	Kestrel ...	12-V. L.C.	5,250	680	2,900	975	1.43
Rolls-Royce...	Buzzard ...	12-V. L.C.	0	955	2,300	1,540	1.61
Hispano Suiza	Y Brs. ...	12-V. L.C.	13,000	846	2,400	1,000	1.18
Curtis-Wright	Conqueror ...	12-V. L.C.	0	775	2,450	1,080	1.40
Gnome Rhone	Mistrol Major	14R. A.C.	0	1,155	2,450	1,205	1.04

Captain Forsyth also wrote that the speed of the air-cooled engine was necessarily lower than that of the water-cooled engine. In the same paper, however, he cited the example of the Napier air-cooled engines which are designed to run at 4,000 r.p.m. This, he believed, was a higher speed than that of any service-type liquid-cooled engine at the present time. Comparisons of engine speed, however, should have been made on the basis of mean piston speed, since that was the real limiting factor. It appeared to him that there was no evidence then that the mean piston speed of air-cooled engines could not be just as high as that of liquid-cooled engines. That view might have to be modified if it were found desirable to increase engine outputs much beyond present levels.

Captain Forsyth's paper lays much stress on engine frontal area and showed the usual diagrams comparing the frontal area of radial and vee engines. Except for purposes of forward vision, it was obvious that frontal area was of importance only as it affected the overall drag of the power plant. Diagrams of this sort which did not show the cooling system necessary for the liquid-cooled engines were likely to be misleading. Even in the case of forward vision, the comparison between the two engines was not indicated by the diagrams. The short length of the radial engine made comparative forward vision better than was indicated by such pictures. The use of frontal area in connection with tandem installations was definitely unsatisfactory, because it was well-known that it was possible to obtain a higher overall propulsive efficiency with two separate nacelles than could be obtained with the best tandem combination.

It was also of interest to note that most of the remarks on future development, and recommendations as to modifications of type tests, applied equally well to both air-cooled and liquid-cooled types, and that any progress made in those directions would not accentuate the advantages of liquid cooling.

Reply to Mr. C. F. Taylor.—He was of the opinion that the mechanical simplicity of the installation as a whole was very little more complicated with a liquid-cooled engine installed compared with that of the air-cooled installation.

Statistics have proved that the majority of installation failures are generally in the fuel systems or the lubrication system. It is true that in the early type of liquid-cooled engines considerable trouble was experienced with water jacket leakages, but the introduction of the latest method of cylinder construction on liquid-cooled engines has reduced this leakage to a minimum. At present the position of the liquid-cooled engine is so good from a water leakage point of view that it can be practically neglected for periods between the complete overhaul of the engines, say approximately 500 or 600 hours. Radiators and water systems have been redesigned to such an extent that the piping required has been reduced to a minimum, thereby removing a great deal of the plumbing which was necessary in the early installations.

In most large air-cooled installations considerable difficulty is experienced in providing satisfactory oil cooling, with the result that large oil coolers, together with increased piping, tends to reduce the reliability of the installation as a whole. In the case of the liquid-cooled types, oil cooling difficulties are not so apparent, and reviewing the amount of piping in both installations, there is very little to choose between the two types of engines.

Mr. Taylor suggests that the air-cooled motor has the advantage of its mechanical simplicity. The Author contends that the present-day air-cooled motor is much more complicated than the latest type of liquid-cooled motor, and that from a maintenance point of view the advantages of the air-cooled motor have disappeared, due to the introduction of superchargers, etc.

He did not agree that the fuel and oil economy under cruising conditions of both types was practically the same, as in his experience it has definitely been proved that due to the liquid-cooled engine being able to use a higher compression ratio than that of the air-cooled type, under cruising conditions, the liquid-cooled engine scores.

In all cases where weights have been given, the power plant installation has taken into consideration the complete weights of the engine, with coolant, etc.

Referring to the air-cooled engines which are designed to run at 4,000 r.p.m., undoubtedly this type of engine scores to a certain extent over the radial air-cooled types by use of exceptionally small cylinders which also allow a high compression ratio to be used, with the result of gain in fuel consumption. If a liquid-cooled engine was constructed on the same lines there would be a further gain, as the liquid-cooled engine can still carry a higher compression ratio with a further gain in fuel consumption, also a liquid-cooled engine of this type can be cowled-in much better than the air-cooled engine, resulting in a gain in speed in the aircraft, as the only head resistance would be that of the radiator.

In discussing the in-line multi-cylinder engines, a great deal seems to be made of the advantages to be gained by the type of cowling used. It is true that the cowling does improve the speed as compared with the machine having an uncowled engine, but in the case of this particular type, owing to the conjected areas between the cylinders, the head resistance of the final installation must be much higher than that of an aircraft where the engine can be completely cowled.

The use of frontal area in connection with tandem installations need not necessarily be unsatisfactory, as in large installations, such as the "Short" flying boat, where it is necessary to carry six 1,000 h.p. engines, it would be

practically impossible to instal six radial air-cooled engines of this h.p. without seriously affecting the performance of the aircraft.

It will be noted from other contributors to the discussion that attempts are being made to produce satisfactory pusher air-cooled engines, obviously with a view to producing a tandem installation or, alternatively, for use in aircraft designed to take pusher airscrews.

He agreed that the recommendations covering the modifications to type test would equally apply to both types.

Mr. H. B. Taylor (Associate Fellow) : In what way was glycol cooling likely to make the lubrication conditions more difficult to cope with, *i.e.*, in what way would the temperature of the inner wall of the cylinder, when glycol was used, compare with the modern air-cooled engine? Hot spots were not unknown in liquid-cooled engines, he believed, and the use of glycol might, in the case of combustion chambers, lead to possible difficulties, such as the promotion of detonation. Had the author any experience on these two points?

Reply to Mr. H. B. Taylor.—The introduction of glycol cooling does make the lubrication conditions more difficult to cope with, as the running clearances have to be increased to practically the same as those applicable to air-cooled engines. There is one decided advantage in this respect which is apparent in the liquid-cooled motor, as it is possible to keep the cylinders reasonably round, whereas in the case of the air-cooled types considerable difficulty is experienced in producing satisfactory scraping, due to the deformation of the cylinders.

Referring to the hot spots which Mr. Taylor claims are not unknown in liquid-cooled engines, this was particularly applicable to the early engines using Poltice heads. In the later types of liquid-cooled engines where there is a free flow of liquid over the whole of the combustion head, very little trouble is experienced with hot spots, provided the exit gallery from the head is placed in the correct position.

It is essential in cases where glycol cooling is going to be used for adequate passages to be provided through the head, particularly round the exhaust branches.

Mr. H. Constant (Associate Fellow) : He would like to press Mr. Taylor's question a little farther and ask whether, if the cylinder wall temperature and the combustion chamber wall temperature were going to be raised in the liquid-cooled engine to those of the air-cooled engine, would the compression ratio have to be brought down to that of the air-cooled engine? If so, would not the water-cooled engine lose much of its advantage over the air-cooled engine in that it could now run at a higher compression ratio? It would also be interesting to know if the oil consumption would go up to that of the air-cooled engine. It rather seemed that if advantage was to be taken of glycol cooling, then the water-cooled engine must relinquish the advantage it had at the moment of a lower fuel consumption and a lower oil consumption.

Reply to Mr. H. Constant.—In putting forward the case for the glycol-cooled engine, it has been suggested that the best temperature to run at would be approximately 130°C. Under these conditions the cylinder wall temperatures are not raised to the extent of that generally experienced in air-cooled motors, but, due to the rise in temperature, a falling off in power of approximately $2\frac{1}{2}$ per cent. takes place.

So far it has not been found necessary to reduce the compression ratio, but it is doubtful if it will be possible to raise the compression ratios to the same extent that would be possible by using water cooling.

The result of experiments to date are not conclusive enough to make a definite statement on this point.

Mr. F. M. Owner (Associate Fellow) : The paper put forward an attractive case for the liquid-cooled engine at the expense of the air-cooled engine, but although the advantages of the liquid-cooled engine had been stressed in some

detail, no mention was made of the corresponding advantages of the air-cooled engine. It was essential to distinguish between the very specialised racing machines which employed the liquid-cooled engine, *e.g.*, the Fiat-Castoldi racing seaplane, and machines of ordinary commercial or service types operating at high speeds.

The Fiat-Castoldi machine which was exhibited in Paris was one complete mass of radiator. The wings, struts, upper surfaces of the floats and every available square inch was radiator, and it was not legitimate to compare such a machine with the ordinary commercial machine. Moreover, the paper compared the liquid-cooled racing engine with the commercial and service air-cooled engine, which did not seem quite a fair comparison. Further, the figures given for the liquid-cooled machine were those which it was hoped to obtain during the next two or three years, but it was not to be supposed that the air-cooled engine would stand still in the meantime. In fact an air-cooled engine—the " Aquila "—had already done a 50-hour test on 73 octane fuel at a b.m.e.p. approximately equal to that of the 1,000 h.p. engine mentioned by the author, viz., 161.

With regard to the frontal area, he wished to press home the point made by the Chairman that the true basis of comparison was the actual drag of the complete aircraft. In many cases in the paper the drag of the engines alone was given, without reference to the drag of the essential extras such as floats, wings, and sundry resistances. If these resistances were included, the comparison figures would be rather different in relation to the air-cooled engine. Neither did the comparisons in the paper include the weight of the water and the weight of the radiator. The only true basis of comparison was the complete installed weight of the whole power plant. In comparing the frontal area of two engines illustrated, he did not include the radiator area. He also showed the advantage of the air-cooled engine in the matter of length; it would be interesting to know if the author really regarded the additional 2ft. as a comparatively small disadvantage of the liquid-cooled engine in the matter of manœuvrability.

With regard to the enumeration of the advantages of the liquid-cooled engine, as set out in the paper, Mr. Owner expressed the view that many of them were common also to the air-cooled engine, and as regards the others he asked the author if he really thought these were solely advantages of the water-cooled engine. Air-cooled pusher engines were known and were functioning. The point had also been raised during the discussion as to engine speed, and in his opinion this is at present limited by the breathing facilities of the cylinder rather than by other mechanical considerations. The problem was to get the gas in and out of the cylinder. Both types of engine presented much the same difficulties in that respect. The air-cooled engine did not freeze, nor did it require any initial warming up.

Again, the output per litre of the ordinary service air-cooled engine was compared in the paper with the liquid-cooled racing engine, but further examples of air-cooled engine advance were to be seen in the " Dagger " with 41 h.p. per litre and the " Aquila " with 30 h.p. per litre. In the case of the 1,000 h.p. engine mentioned towards the end of the paper, this appeared to have a percentage loss for the blower of only 3 per cent., which seemed a very small deduction for 3,000 r.p.m. even at ground level, and for any altitude it would have to be much higher.

The author had mentioned, in connection with liquid-cooled compression ignition engines, a specific weight of 3½lbs. per h.p., but this was well beaten by existing air-cooled compression ignition engines. The published details of the Phœnix engine, which held the altitude record for this type of engine and which had been flight tested, showed a figure of less than 2½lbs. per h.p.

Referring to the " Jumo " C.I. engine, Mr. Owner pointed out that in the paper it was said this could be laid on its side in the wing, but it was an interesting fact that at the Paris Salon the " Jumo " engine was mounted

vertically, which suggested there might be some compelling reason why this engine should not be laid on its side.

The paper set forth the superiority of the radial supercharged engine over the line engine in the matter of fuel distribution, and certain new developments might make this a matter of the highest importance.

Fan-cooled engines were a development from which much was to be expected and in the direct fan air-cooled engine there were possibilities of combining the advantages of low drag and air cooling.

In conclusion, Mr. Owner said that improvements would undoubtedly be made in the liquid-cooled engine and its installation. It would not stand still any more than would the air-cooled engine, but he felt that for fast commercial and service aircraft liquid-cooled engines would never have the simplicity, reliability and general balance of the air-cooled engine.

Reply to Mr. F. M. Owner.—It is obvious that the Fiat-Castoldi aircraft which was exhibited at Paris was completely covered with radiators, as the dimensions of the aircraft had been reduced to a minimum, and the engine was developing somewhere in the region of 2,500 b.h.p.

In putting forward the case for the liquid-cooled engine, one must assume that it was intended in connection with improving service aircraft and was not intended to cover freak machines.

It is also stated in the paper that it has been found possible by using glycol cooling to reduce the size of the radiator to approximately one-third of the size required for water cooling. As far as the author's experience goes, even the standard water-cooled radiator does not cover the whole of the aircraft, and is generally a very small percentage of the frontal area.

There is no doubt that the development of the air-cooled engine is well advanced, but no matter how it advances, the liquid-cooled motor can generally go one better.

He agreed with Mr. Owner that the actual drag of the complete aircraft had to be considered, and he further contended that the drag of the complete aircraft was considerably influenced by the drag of the engine installation. Obviously, a great deal could be done to improve the drag of the complete aircraft by greater attention being given to the fairing in of floats, etc. The fairing in of such components applies equally well to both liquid- and air-cooled types.

He further agreed that the comparison should include the weight of the water and of the radiator; in all cases this had been done where mention is made of complete installations.

Regarding the overall length of the air-cooled engine, referring to Fig. 6 which shows the side elevation of a liquid-cooled and air-cooled single bank radial, the overall length of the liquid-cooled engine is approximately 2ft. over that of the air-cooled type, but when double bank radials are used, the difference in length is only approximately 1ft., and in some cases where inertia starters are used at the rear of the engine, the difference in overall length is little more than 6in.

Further, in some installations it has been found necessary to instal the air-cooled engine slightly further forward than would be necessary with an uncowled engine to take full advantage of the modern cowling. This detracts from the advantages claimed for the air-cooled engine from a manœuvrability standpoint.

Compression ignition engines are still in their early stages of development, and the author agrees that the figures obtained from the " Phœnix " engine are splendid. He still considers, however, that the liquid-cooled engine should eventually find its position in this field, particularly in large commercial aircraft, as engines at present running have a fuel consumption as low as 0.36. This figure he believes is lower than that obtained from the " Phœnix " engine.

Regarding the weight per b.h.p., the figure of 3½lbs. quoted was the figure which the author expected could be obtained easily and undoubtedly with extensive development, it would be possible to still further reduce this figure. He agreed that fan-cooled engines were worthy of development and he expected that at some future date, this type of engine would probably alter all our views in connection with engine installation.

Mr. W. P. SAVAGE (Associate Fellow) (*communicated*): The case for the liquid-cooled engine as presented in the paper appears to be stronger than it really is. One of the chief reasons for this is that in all his comparisons with the air-cooled engine the author neglects the in-line air-cooled engine, except for a passing reference to the engines in the De Havilland "Comet." Possibly the author is right when he says that liquid-cooled engines will be used for some time to come, when ultra high speeds are required, and by that, I take it, that he means racing machines. In no other type of aeroplane can it be justly claimed that the in-line air-cooled engine cannot equal the performance of the liquid-cooled engine.

Some of the specific statements in the paper are made without evidence to prove their reason. As, for instance, the author declares that in his opinion, it may be necessary to revert to liquid-cooled engines when powers over 700 are required. On what grounds is such a sweeping statement made?

It cannot be on the grounds of small frontal area, for to-day there exists an air-cooled engine, the Napier-Halford "Dagger," which develops 760 horse-power at 12,000 feet, representing over 100 horse-power per sq. ft. of frontal area. In connection with this point of frontal area, he would like to know whether the radiator is included in the figures quoted in respect of the liquid-cooled engine.

It cannot be on the grounds of lower specific fuel consumption, unless the author has succeeded in obtaining on his own engine a figure much lower than those now agreed upon by the Air Ministry for tankage calculation.

It cannot be on the grounds of simplicity of installation, for, to use the phraseology of the paper, "piping running everywhere in the fuselage," is not conducive to a simple and easily maintained installation, and whilst it must be agreed that water-cooled systems have been simplified, cylinder jackets, water pipes and radiators are still vulnerable to gunfire. When one comes to an evaporative cooling system, the position is no better for, although leakage from one puncture will be a good deal less, the greatly increased cooling area necessary means that it is practically certain that the surface coolers will receive many more punctures than one. One has only to look at the Italian speed record machine to realise that such a machine has a very poor chance of getting through an anti-aircraft barrage, or carrying on a prolonged fight with other machines. For military machines evaporative cooling would seem to increase the vulnerability of the liquid-cooled engine. For civil purposes liquid-cooled engines do not exist, presumably owing to the high cost of curing and preventing the water leak.

Other points quoted in favour of liquid-cooled engines, such as the position of the thrust line, the housing of a V.P. airscrew, etc., can be arranged just as conveniently on the in-line air-cooled engine.

Captain Forsyth also claims the advantages to the liquid-cooled engine of high engine speeds. Is it not a fact that the only high speed aero engines existing in type tested form to-day are air-cooled engines? As is well known, the normal speed of the "Dagger" and "Rapier" engines is 3,500 r.p.m. with a maximum of 4,000 r.p.m.

Hitherto the liquid-cooled engine has generally shown a lower oil consumption than the air-cooled engine, and the latter has often been referred to, colloquially, as an oil-cooled engine. To show that this is no longer the position, he would like to mention that on a type test recently carried out on the

" Dagger " engine, the specific oil consumption was 0.009 pints/b.h.p./hour for the duration running, and 0.014 pints/b.h.p./hour for the high power running. These figures are equal to any hitherto published in relation to a liquid-cooled engine.

In the section on " increase of power," the figures quoted for the " Dagger " engine refer to the Series I engine. The output of the Series II " Dagger " at maximum r.p.m. is equivalent to 46 horse-power per litre capacity at an altitude of 12,250 feet.

Finally, with reference to the lower standard of performance of British machines compared with that obtained in America, this is not the fault of the engine. British engine technique is at as high a standard as American engine technique. It is up to the aeroplane designer in this country to improve the technique of aeroplane design instead of clamouring for more power and more power, in order to reach American performances. Increased speed obtained by aerodynamic refinement is much less costly than a similar increase obtained by brute force alone. That it is possible to produce a fast aeroplane with air-cooled engines has been proved by Captain De Havilland with his " Comet," and if the American engine builder had not neglected the development of the in-line air-cooled engine, the difference in speed between American machines and their own would have been still greater.

Reply to Mr. W. P. Savage.—He had already stated that the in-line engine had advantages compared with those of the radial type, but was of the opinion that there would be a limitation to the cylinder size until such time as it was possible to produce a satisfactory completely enclosed air-cooled engine.

The figure of 700 b.h.p. referred to was intended to be the normal b.h.p. of the engine—not the maximum, as stated by Mr. Savage. The figure of 100 b.h.p. per sq. ft. of frontal area can be improved upon by properly installing a liquid-cooled engine using glycol cooling.

A strong point is made of the vulnerability to gunfire as applied to aircraft with liquid-cooled engines installed. In considering this point the engine must be left out as a bullet entering a cylinder in either type would put the engine out of action. If Mr. Savage will examine the diagram of a modern liquid-cooled installation, it will be noted that very little is added to the area which could be effected by gunfire by the use of liquid-cooling. Radiators of the block tube type generally close up where the bullet enters the radiator, and this leaves the piping and header tank to be considered. In the case of the header tank, the engine could be expected to continue running satisfactorily, whereas if the water piping itself was punctured, undoubtedly a seizure would take place.

The obvious thing to do is to produce aircraft which is fast enough to outclass any rivals, and to provide as far as possible the most simple installation.

The statement made that the only high speed aero engines existing in type tested form to-day are air-cooled engines is apt to be misleading, as the rotational speed of 4,000 r.p.m. does not truly indicate the piston speed. In the case of the " Dagger," this is approximately 2,500 ft. per min., whereas a well-known liquid-cooled engine has completed type test with a piston speed of 2,750ft./min., and in the case of the " R." engine the piston speed was approximately 3,500ft./min.

He agreed that the oil consumption quoted was excellent, and would be difficult to beat on any type of engine.

He was also in full agreement with the last paragraphs relating to further development being continued with a view to improving the aerodynamic qualities of aircraft without using unduly powerful engines.

ABSTRACTS AND NOTICES

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(*Prepared by R.T.P.*)

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Aircraft—Design, Performance, etc.

Comparison between Douglas DC2 and a Projected French Aircraft. (L. Breguet, L'Aéron., No. 181, June, 1934, pp. 127-130.) (5.10/29301 France.)

The high performance of the Douglas aeroplane (manufactured under licence by Fokker) is attributed to careful design on well-known lines, with freedom from restrictions imposed by external authority.

Modern Fighting Aircraft. (H. Ritter, Z.V.D.I., Vol. 78, No. 15, 14/4/34, pp. 455-458.) (5.10/29302 Germany.)

Leading types of French fighting aircraft are described and illustrated, ranging in weight from one to four tons, with a corresponding h.p. range from 500 to 1,800 h.p.

Great attention is given to cone of fire and protection of gunner from wind and weather, which is essential at high speeds. The author expresses the opinion that defensive armament has been unduly developed at the expense of offensive capacity.

Coupe Deutsch de la Meurthe, 1934. (Flugsport, Vol. 26, No. 12, 13/6/34, pp. 241-242.) (5.10/29303 France.)

The winning machine reached 240 m.p.h. with a six-cylinder 315 h.p. in-line Renault engine. The average fuel consumption was 6½ miles per gallon. At these high speeds the smaller resistance gives a definite advantage over the single bank air-cooled radial engine of equal power. This advantage might be reduced by the development of the two-bank radial, with reduction of the over-all diameter and head resistance.

Temperature measurements in flight indicate the need of equalisation of cylinder air-cooling. The rear cylinder of the in-line engine tends to overheat and there are always one or two cylinders in a radial engine which are appreciably hotter than the others. (See Abstract 29346.)

The Aerodynamic Effects of Wing Cut-away. (A. Sherman, N.A.C.A. Report No. 480, 1934.) (5.20/29304 U.S.A.)

A method is developed for estimating the effect of wing cut-outs, which gives a reasonably good fit with tests in the variable density wind channel.

Increase of the dimensions of the cut-out parallel to the chord has much greater effect than increase along the span. Fairing is necessary along the edge of a cut-out.

Nine references.

Influence of Cut-away in Elevator on Longitudinal Stability and Elevator Control. (C. Biechteler, L.F.F., Vol. 11, No. 1, 15/5/34, pp. 1-4. D.V.L. Report No. 33/01.) (5.20/29305 Germany.)

The yawing moment of the rudder of a light aeroplane required to be increased and this was effected by cutting away a sector in the elevator to allow of increase in the rudder depth, reducing the area by 12.5 per cent. Photographs and sketches show the modification.

The aeroplane was equipped with measuring instruments and put through a series of tests in steady flight at different speeds with four different positions of the C.G., first with the standard elevator and rudder, then with the modification. The relations between indicated speed control, lift, moments, incidence and position of C.G. at full power and in glide are shown graphically for those of parameters taken in pairs.

The stable range of the centre of pressure was reduced by 1.8 per cent. at full throttle and by 1.3 per cent. for gliding. The control forces could not be measured. The static control of the elevator was decreased by 22 per cent. at full power and 10 per cent. running light.

Two references.

Caretta System of Rigid Transmission Controls. (L'Aéron., No. 179, April, 1934, p. 70.) (5.356/29306 France.)

A small cylindrical gear box of circular section is divided into two equal cylindrical parts which abut and are clamped in position by an axial bolt and end plates. The two halves of the gear box can be rotated relatively to each other before clamping so that two inter-geared control rods may be set at any angle to each other. A complete transmission gear weighs about $\frac{1}{4}$lb. and transmits a thrust of 70lb. weight.

Aircraft—Landing Gear, Hulls, etc.

Semi-Automatic Brakes for Aeroplanes. (G. A. Boggio, Riv. Aeron., Vol. 10, No. 5, May, 1934, pp. 258-267.) (5.53/29307 Italy.)

The brakes are operated by oil pressure, governed by the contact pressure between tail skid wheel and ground.

Retractable Undercarriage "Charlestop." (L'Aéron., No. 182, July, 1934, pp. 172-174.) (5.555/29308 France.)

A mechanism, actuated by oil pressure, swings back a leg and folds it towards the centre. Each leg is handled separately on account of the complicated motion. The gear weighs about 30lb. Sluggish action of the oil and deformation of the landing gear have caused defective working.

Airscrews

Working Charts for Determination of Airscrew Thrust. (E. P. Hartman, N.A.C.A. Report No. 481, 1934.) (5.60/29309 U.S.A.)

A "torque speed" coefficient is defined as the quotient of the V/nD ratio by the square root of usual torque coefficient, and is plotted against the ratio

thrust coefficient/torque coefficient. On the assumption that the engine torque is constant, the charts enable the thrust to be read off for any value of V/nD.

Twenty-four tables of airscrew data are reprinted from Technical Report No. 350 and exhibit airscrew characteristics for mean blade pitches from 10° to 28°.

Three references.

Some Dynamical Characteristics of Propellers. (J. Morris, J.R. Aer. Soc., Vol. 38, No. 288, Dec., 1934, pp. 987-997.) (5.63/29310 Great Britain.)

General expressions are written down for forces and moments of inertia of blades. A simplified blade form is assumed, the solution of the differential equation of bending vibration is developed in series for first and third approximations. Numerical values are found for the blade form assumed. Alternatively, Rayleigh's approximate method is applied and numerical results are given.

Torsional vibrations are discussed for a simple case and the results are extended to a crankshaft with many throws.

Variable Pitch Airscrews. (L'Aéron., No. 182, July, 1934, pp. 175-182.) (5.64/29311 France.)

Details and method of operation of the Ratier and Levasseur propeller are given, with illustrations. There are two working pitches, coarse and fine. In the Ratier the change of pitch is governed automatically by air pressure increasing with flying speed. In the Levasseur, the change of pitch is governed partly by engine speed and partly by hand control.

Reduction of Energy Losses in Channels by Guide Vanes. (K. Frey, F.G.I., Vol. 5, No. 3, May/June, 1934, pp. 105-117.) (5.644/29312 Germany.)

Twenty-one forms of channels with sharp turns are shown in sketches, with principal dimensions, and the losses in the bends with and without guide vanes are tabulated.

Fifteen photographs show the fundamental differences in the configurations of flow with and without guides and general principles are deduced for the disposition of the vanes.

Twelve references.

Two-Spar Wing Structure with Ribs. (C. Minelli, L'Aerotecnica, Vol. 14, No. 5, May, 1934, pp. 493-531.) (5.660/29313 Italy.)

The author investigates the stiffness of two spar wings, both when unsupported (cantilever) and when fitted with external supports. The critical speed is calculated.

Instruments

A New Oscillograph. (E. S. Shire, J. Sci. Inst., Vol. 11, No. 12, Dec., 1934, pp. 379-384.) (6.0/29314 Great Britain.)

Author's Abstract.—This paper describes a new type of oscillograph in which the moving part consists of a very light single turn coil suspended without torsional control in a constant magnetic field. No leads are attached to the coil, but energy is supplied to it by making it the secondary winding of a transformer, the primary of which carries the current to be recorded. The instrument is rapid, dead beat and of high sensitivity.

Four references.

Airscrew Vibration Indicator. (H. L. Dryden and L. B. Tuckerman, Bur. Stan. J. Res., Vol. 12, No. 5, May, 1934, pp. 537-542.) (6.0/29315 U.S.A.)

Failure of airscrews is attributed to fatigue under alternating forces.

An electro-magnetic indicator was designed for direct record of vibrations of any working combination of engine and airscrew. In principle two coils

carrying a direct current maintain a fixed relative position in steady rotation, but are periodically displaced when harmonics are present. An alternating current is superposed in the direct current and may be separated by a transformer.

A diagram shows a record from 20 to 150 cycles per second. The indication in milliamperes is plotted and shows well defined peaks at synchronism, with the fundamental and with the first harmonic.

An Electric Manometer for Pressure up to 3,000 Atmospheres. (A. Michels and M. Lenssen, J. Sci. Inst., Vol. 11, No. 11, Nov., 1934, pp. 345-347.) (6.251/29316 Great Britain.)

Authors' Abstract.—The construction of a differential electric manometer depending upon the variation of resistance of manganin coils with pressure is described. A special form of plug resistance is employed in the bridge circuit, whereby the number of plugs in use is always the same, thus decreasing variation due to contact resistance.

Six references.

Measurement of Gas Quantities in Standard Cubic Metres. (J. F. Schutz, Z.V.D.I., Vol. 78, No. 29, 21/7/34, pp. 875-877.) (6.252/29317 Germany.)

For measurement of large quantities of gas the rotary meter of the Roots type is receiving increasing attention. The number of revolutions is a measure of the volume of gas passing. An aneriod controls the revolution counter and the volume is recorded at standard temperature and pressure.

Automatic Pressure Regulator. (W. Pontow, Z.V.D.I., Vol. 78, No. 28, 14/7/34, pp. 848-850.) (6.252/29318 Germany.)

The regulator is intended to keep the gas pressure in a supply system constant. It consists essentially of a pressure gauge, the pointer of which makes electrical contacts when the pressure exceeds or falls below a certain amount. Freedom from hunting is maintained by a linkage which moves the contacts relatively to the pointer.

One reference.

The Time Balance—An Instrument for Comparing Time Rates of Watches. (R. Tamm, Z.V.D.I., Vol. 78, No. 18, 5/5/34, pp. 556-558.) (6.3/29319 Germany.)

The rates are compared acoustically by arranging two microphones with amplifiers in a bridge circuit with the grids of two relay valves. The microphones respond to the ticks of the two watches and the relay valve produces an out of balance current depending on the phasing of the ticks. The instrument will detect a difference in time rate of the order of 10 seconds in 24 hours.

One reference.

High Vacuum Ballistic Galvanometer. (W. B. Ellwood, Bell Tele. B-808, 1934.) (6.35/29320 U.S.A.)

By suspension in a high vacuum and by various modifications a sensitivity of one millimetre deflection is obtained for one metre scale distance and four Maxwell turns, which is above 125 greater than commercial galvanometers.

Details of construction are given and the performance characteristic is discussed.

Fourteen references.

Aerodynamic Investigation of a Cup Anemometer. (J. D. Hubbard and G. P. Brescoll, N.A.C.A. Tech. Note No. 502, July, 1934.) (6.40/29321 U.S.A.)

The normal force coefficients were determined statically for :—

(1) Single cup with no interference.
(2) Single cup with interference from three cups.
(3) Four cups.

The coefficients of a single cup with three-cup interference are nearly all greater than without interference, indicating that the coefficient of resistance increases in turbulent flow.

Seven references.

Modern Drift and Ground Speed Indicators. (Lt. Aussenac, L'Aéron., No. 179, April, 1934, pp. 77-82.) (6.51/29322 France.)

The development of drift and ground speed indicators is treated chronologically. The Wimperis and Zeiss instruments are described in detail. As altitudes increase an optical sighting system becomes more necessary. The development of suitable instruments is influenced by artillery requirements.

Haya Control Instrument for Blind Flying. (L'Aérophile, Vol. 42, No. 5, May, 1934, p. 151.) (6.52/29323 France.)

A mechanism controlled by two air driven gyrostats indicates the position of the aircraft relatively to the ground, by the position of a model relatively to the cockpit.

Suction Driven Gyroscopes for Aircraft Instruments. (C. S. Draper and A. F. Spilhaus, Trans. A.S.M.E., Vol. 56, No. 5, May, 1934, pp. 289-294.) (6.52/29324 U.S.A.)

The elementary theory of venturi tube arrangements for providing air drive is discussed and diagrammatic sketches show the general disposition of the details of a double venturi tube with pipe connections for flight tests. Experimental relations between venturi dimensions, pitot pressure, air speed, air flow, altitude and effective orifice, taken in pairs, are shown graphically as characteristic curves.

Pump characteristics are also shown. The pump is considered as superior to the venturi tube. The low efficiency, poor flight-speed characteristic and liability to ice formation of the latter offset its simplicity, reliability and cheapness.

Three references.

Peak Accelerometer. (Z.V.D.I., Vol. 78, No. 27, 7/7/34, pp. 835-836.) (6.73/29325 Germany.)

A rod, free to move axially, is placed against the vibrating body, and transmits the motion to a mass mounted eccentrically on the axis of a flywheel and carrying a sliding electrical contact. A pointer, set on the common axis, is controlled by a spring. An initial tension can be found for which the pointer is not deflected by the vibration and this is a measure of the maximum acceleration of the rod. Maximum acceleration up to 10m. sec.$^{-2}$ can be measured.

For extensive bibliography on this and similar instruments, see Z.V.D.I., Vol. 76 (1932), p. 1065.

Aircraft Flight

Flying Boats for Ocean Transport. (W. W. Webster and W. D. Clark, J. Aer. Sci., Vol. 1, No. 2, April, 1934, pp. 55-65.) (7.15/29326 U.S.A.)

A general descriptive account is given of the problem. Typical seaplane and flying boat types are shown in outline.

Tables of comparative weights and graphical representations of the relation between loads, total weights and range are reproduced.

General conclusions are drawn of a familiar nature.

Estimation of the Variation of Thrust Horse-Power with Air Speed. (S. Ober, N.A.C.A. Tech. Note No. 446 (Appendix), July, 1934.) (7.15/29327 U.S.A.)

The method of Technical Note 446 is extended to the case where the brake horse-power of the engine varies non-linearly with the speed. (See Abstract 28018.)

Separation of Roots in Stability Problems. (K. Th. Vahlen, Z.A.M.M., Vol. 14, No. 2, April, 1934, pp. 65-70.) (7.20/29328 Germany.)

References are given to various steps in the generalisation of Sturm's method for separating real roots along an axis and to separation of complex roots in the Argand plane.

Contour integrals of the complementary functions along the circumference and vertical axis of a sufficiently large circle give the number of roots in the right and left hand semi-circles.

Parallel shifts of the vertical axis determine the number of roots in a strip of the Argand plane. If the conditions of the problem are modified so that the corresponding shift of the y-axis places all the roots in the left hand semi-circle, the real parts of all the roots are negative and satisfy a condition of stability.

The quotient of the complementary functions is expressed as a continuous fraction, each successive partial quotient being one degree lower than the preceding. These lead to new criteria; in particular, if the continued fraction terminates before the last partial quotient is of zero degree, there must be equal roots. New formal criteria are obtained for the distribution of roots.

A simple formal illustration is given for a quadratic with complex roots.

(In the absence of numerical examples with equations of higher degree, it is difficult to assess the practical value of the method. No reference is made to Graeffe's method and subsequent developments. See Abstract 7973 *re* Brodetsky and Smeal, Proc. Camb. Phil. Soc., XXII, Part II, 1924.)

Four references.

Further Measurements of Longitudinal Stability. (W. Hübner, L.F.F., Vol. 11, No. 1, 15/5/34, pp. 5-15. D.V.L. Report 33/02.) (7.25/29329 Germany.)

A. A Junkers F.13 ge, shown in outline sketches, was flown with different positions of c.g., and the elevator incidence, indicated flying speed, wing incidence, height and span were measured in steady flight at seven throttle positions, including full power and light running. At full power useful readings were obtained up to a lift coefficient of $Ca=1.2$ ($k_L=0.6$) and in gliding flight only up to $Ca=0.6$ ($k_L=0.3$), between which limits active rudder control was necessary.

The relations between elevator angle, lift, control moment, flying speed and span are exhibited graphically between pairs of variables. The induced velocity is also shown as a function of lift at full throttle and running light. The effects on stability are shown in a more comprehensive figure (10). At full throttle small changes in the elevator angle gave large changes in the lift. Running light, the elevator moment is much less sensitive to angular changes. With fixed elevator position the lift increases very rapidly with opening throttle and this should be considered in elucidating certain accidents.

Other conclusions are drawn. Six references.

B. The influence of the hinge inertia moment of the elevator on longitudinal stability is discussed. Earlier measurements show that the longitudinal stability increases with the weight moment of the elevators left free. Blenk has given a mathematical demonstration of this result.

An extension of the experimental work was carried out to confirm the results and to bring out the underlying principles. The same aeroplane as in " A " was tested with three different values of the elevator hinge inertia moment, at full throttle and running light.

The elevator control mechanism is shown in dimensioned sketches, with specification of weights and c.g. position. The relations between control lever and elevator displacements, elevator weight moment and force on lever, lift and incidence pitching moment, are shown in diagrams for three weight moments.

The restoring moments are plotted for full and light throttle for the three cases and show a systematic increase of longitudinal restoring force with weight moment.

Three references.

Seaplane Take-off Weights. (E. T. Jones, Airc. Eng., Vol. 6, No. 70, Dec., 1934, pp. 330-332, and No. 71, Jan., 1935, pp. 8-10.) (7.30/29330 Great Britain.)

Typical characteristic curves of resistance and incidence as functions of flying speed are given. Resistance attitude and moment attitude characteristics are also given.

A discussion is given of the effects on performance of varying the characteristics separately.

Finally, characteristic curves near the limiting weight are discussed and methods of decreasing the peak value are considered.

Motion of Flying Boats during Take-off and Landing Run. (T. Ogawa and J. Murata, Aer. Res. Institute, Tokyo, Report No. 105 (Vol. 8, No. 9), April, 1934.) (7.30/29331 Japan.)

From English Abstract.—Data are presented from full-scale experiments on the " N " and " Dornier Wal " flying boats.

Coefficients of water resistance, trim and heaving are given graphically and in tables, for landing and starting runs, and model data are given graphically for comparison. The maximum values of water resistance agree fairly well for model and full-scale, but beyond the hump the full-scale figures are much lower. The resistance curves for starting and landing runs differ considerably. The hump speed is less for a flat bottom (Wal) than for a wedge bottom (N).

The text is in Japanese, but most of the data and figures have headings in English.

Landing Shock Recorder. (M. J. Brevoort, N.A.C.A. Tech. Note No. 501, July, 1934.) (7.30/29332 U.S.A.)

A weight slides freely in a cylinder and actuates a mirror. The restoring force is supplied by a spring, the natural frequency being of the order of 1.5 cycles per sec. A beam of light reflected from the mirror gives a record of the decelerations, which are smaller than had been assumed.

A Criticism of the Term " Landing Speed." (E. Everling, Luftwissen, Vol. 1, No. 4, 15/4/34, p. 106.) (7.30/29333 Germany.)

Landing shocks from irregularities on the ground are proportional to the square of the landing speed. The ratio between maximum horizontal flying speed and minimum landing speed gives no indication of landing shocks or the length required to pull up. Elementary mathematical relations are written down to illustrate the argument.

One reference.

Slotted Wings. (W. Pleines, Luftwissen, Vol. 1, No. 6, 15/6/34, pp. 152-157, and No. 7, 15/7/34, pp. 190-197.) (7.72/29334 Germany.)

A summary is given of the present state of model wings alone and test characteristics of complete aeroplanes are tabulated. A direct comparison between full-scale and model of the Bristol Fighter is also quoted.

The effective incidence and lift distributed along the span are shown graphically, with unslotted wings and with slotted wings, the latter from Lachmann's calculations. English measurements of the coefficient of rolling moment are shown as functions of incidence for ordinary wings, wings with slots and wings with end slots. The lift coefficient is also shown as a function of incidence for the wing, as a whole and for the slotted part only, with slots opened and closed. American measurements of lift and rolling moment coefficients are shown graphically as fractions of incidence.

A tabular form shows the qualitative relation between roll angle, angular velocity and angular accelerator and time, according as the lift coefficient is below maximum, at maximum and above maximum.

Expert opinion on the value of slots is contradictory and interpretations of their action is ambiguous.

Nineteen references.

Wind Tunnel Measurements of Air Loads on Split Flaps. (C. J. Wenzinger, N.A.C.A. Tech. Note No. 498, May, 1934.) (7.72/29335 U.S.A.)

Measurements of control forces necessary to operate split flaps show hinge moment coefficients more than twenty times that of a normal aileron. Possible reduction of the hinge moment is under investigation.

Five references.

Zap Flaps and Ailerons. (T. N. Joyce, Trans. A.S.M.E., Vol. 56, No. 4, April, 1934, pp. 193-201.) (7.72/29336 U.S.A.)

The Zap wing flap designed by Mr. E. F. Zaparka is hinged in front of the trailing edge and extends over the full span of the wing. On opening, the hinge travels forward and the average V-shaped space between wing and flap is filled with substantially " dead " air. The ailerons are set above the wing. The advantage is claimed of rapid operation with small effort. The increase in lift is over 80 per cent.

With ordinary aeroplanes skilled judgment is required in flattening out for landing. In certain types of lightly loaded sport machines it is claimed that the Zap flap enables the pilot to set the machine in an altitude in which it glides with engine off on to the ground, without any manœuvring of the controls.

Automatic Control of Aeroplanes. (Sci. Am., Vol. 151, No. 1, July, 1934, p. 36.) (7.50/29337 U.S.A.)

A photograph shows the principal parts of a G.E.C. steering installation controlled by external wireless. Corrections are made for drift and course error. The effective range is given as 150 miles.

Observations on Spins. (J. M. Gwinn, Trans. A.S.M.E., Vol. 56, No. 6, June, 1934, pp. 393-400.) (7.62/29338 U.S.A.)

The aerodynamical causes of spin are discussed and some test figures are quoted giving number of turns required to come out of a spin.

The concise summary of the mathematical theory is given.

Eight references.

Engines—Thermodynamics

The Process of Combustion in the High Speed Engine. (W. Kann and P. Rickert, Z.V.D.I., Vol. 78, No. 28, 14/7/34, pp. 851-855.) (8.13/29339 Germany.)

A brief review is given of methods of investigating processes of combustion in an engine cylinder, *e.g.*, ionisation, photographic flame and pressure records and chemical analysis of samples from a sampling valve.

Special attention is given to the two stage ignition engine and diagrams taken with a quartz indicator show pressure differences between the precombustion chamber and the main cylinder.

Nine references.

Heats of Combustion and of Formation of Paraffin Hydrocarbons. (F. D. Rossini, Bur. Stan. J. Res., Vol. 13, No. 1, July, 1934, pp. 21-35.) (8.13/29340 U.S.A.)

The heats of combustion of normal hydrocarbons in the gaseous state are calculated. The addition of the CH_2 group to the normal alkyl group results in an increase in the heat of combustion of 157 kcal (gaseous state, 25°C., and one atmosphere), provided the original alkyl group contained more than five carbon atoms.

Twenty-six references.

Determination of the Specific Heat of Gases at High Temperatures by the Sound Velocity Method. I. Carbon-monoxide. (G. G. Sherratt and E. Griffith, Proc. Roy. Soc., Vol. 147, No. 861, 15/11/34, pp. 292-308.) (8.13/29341 Great Britain.)

Experiments on the velocity of sound for frequencies 7,908 and 27,422 respectively show an increase of approximately 2 per cent. at the high frequency at temperatures between 1,000°C. and 1,800°C. On the assumption that the difference is due to partial failure of the vibrational energy to follow the acoustic cycle, a true specific heat value can be calculated which is in good agreement with spectroscopic data.

Fifteen references.

Specific Heat of Gases and Vapours at High Temperatures. (E. Justi, F.G.I., Vol. 5, No. 3, May/June, 1934, pp. 130-137.) (8.13/29342 Germany.)

A survey is made of available methods, including explosion, adiabatic flow, velocity of sound and spectroscopic methods. Collected results are tabulated.

The problem of dissociation is discussed and the relevant chemico-thermal equations with numerical coefficients are given for thirteen gases and vapours.

The work of compilation was undertaken for the German Standards Committee.

Forty-three references.

On the Composition of Exhaust Gases from Petrol and Petrol/Alcohol Mixtures. (J. Formánek, Autom. Tech. Zeit., Vol. 37, No. 9, 10/5/34, pp. 234-238.) (8.15/29343 Germany.)

On light load and low speeds the engine exhaust contains appreciable quantities of oxides of nitrogen.

One reference.

Engines—Design and Performance

Aero Engine Installation. (R. G. Pettit-Herriot, Airc. Eng., Vol. 6, No. 69, Nov., 1934, pp. 285-290, and No. 70, Dec., 1934, p. 332.) (8.20/29344 Great Britain.)

Statistics show that the majority of engine failures resulting in forced landings are due to faulty engine installation. The article gives examples of satisfactory installation of water-cooled and air-cooled engines, with excellent illustrations.

Aero Engine Design in 1934. (M. Lagarde, Rev. Gen. L'Aéron., No. 17, pp. 85-129, and No. 18, pp. 55-88.) (8.20/29345 France.)

Superchargers are becoming standard equipment and details are given of Continental practice. Castor oil is generally used in French aero engines as a home product of consistent quality. Its deterioration can be controlled and methods have been devised for rapid determination of ageing of samples. Castor

oil withstands high temperatures for a short time, but under continuous high temperature operation carbon deposits, gummed rings, etc., entail shorter periods between overhauls.

It is of interest to note that most of the French engine firms design both water and air-cooled models. The two banked 14-cylinder radial is receiving special attention.

Renault Six-Cylinder Coupe Deutsch Engine. (Flugsport, Vol. 26, No. 13, 27/6/34, pp. 277-278.) (8.20/29346 Germany.)

The inverted six-cylinder, in-line, air-cooled engine (110 × 140) of 8 litre capacity is rated at 300 h.p. at 3,000 r.p.m. A centrifugal fan delivers compressed air to a Stromberg down-draught carburettor.

Analysis of Motion of Master and Auxiliary Connecting Rod Assembly. (K. Schlaefke, Z.V.D.I., Vol. 78, No. 27, 7/7/34, pp. 831-834.) (8.20/29347 Germany.)

The auxiliary rod assembly involves a displacement of the dead centre position and a change in stroke of the corresponding auxiliary piston, which may affect the torsional vibration characteristics of the complete engine.

One reference.

Engine Installation of SS. "Konigin Luise." (B. Bleicken, Z.V.D.I., Vol. 78, No. 20, 19/5/34, pp. 603-606.) (8.21/29348 Germany.)

The engine is single acting two-stroke, with direct injection. Quiet running is obtained by fitting a silencer to the air intake of the scavenge blower, which is of the Roots type, and a two stage silencer to the engine exhaust. The blowers take air directly from the engine-room as a long intake pipe produces vibration and noise. Part of the engine silencer consists of concentric tubes. The inner tube is perforated and the sound waves enter the annular space and are damped by a packing of copper turnings.

The piston is very long, the gudgeon pin being placed abnormally low. Canting of the piston is prevented by fitting special rings of silumium.

Three references.

Investigation on the Scavenging Process of Two-Stroke Engines. (C. Zublin, W.R.H., Vol. 15, No. 13, 1/7/34, pp. 175-177.) (8.21/29349 Germany.)

The scavenging process is investigated in two and three-dimensional flow models. The direction of the air motion is indicated by means of small flags and the velocity is measured with a pitot tube. The results are not directly applicable to design as they do not take into account piston motion and differences in temperature between exhaust gas and fresh charge.

To some extent differences in density can be allowed for by filling the model with coal gas and scavenging with air. An analysis of the charge in the model after the scavenging is complete gives an indication of the effectiveness of the process. An obvious development is to take samples on the engine itself, with a special sampling valve, during the compression strokes. The problem is extremely complex, the type of gas flow and the resultant exhaust dilution varying considerably between successive explosions.

Tests on an Internal Combustion Engine with Variable Piston Stroke. (J. Schmitt, Autom. Tech. Zeit., Vol. 37, No. 13, 10/7/34, pp. 336-340.) (8.22/29350 Germany.)

The crank throw and big end are in the form of an eccentric and strap with roller bearings. Axial movement of a concentric lay shaft actuates a screw drive which alters the eccentricity and stroke and, at the same time, raises or lowers the cylinder so that the compression ratio is kept constant for all strokes.

The experimental engine had a single air-cooled cylinder of 60 mm. bore. The stroke could be varied between 28 and 84 mm. A slight gain in thermal efficiency was obtained at low power (reduced stroke and full throttle) in comparison with a normal engine throttled down (full stroke and reduced charge).

The Volumetric Efficiency of High Speed Four-Stroke Engines. (E. Drucker, Autom. Tech. Zeit., Vol. 37, No. 14, 25/7/34, pp. 350-363.) (8.22/29351 Germany.)

An attempt is made to calculate volumetric efficiency, taking into account heat exchange and pressure changes in the engine. The figures show an appreciable decrease of volumetric efficiency with increase in compression ratio.

Twenty-six references.

External Compression Process for Diesel Engines Intended for Locomotive Drive. (S. Grantz and P. Rieppel, Z.V.D.I., Vol. 78, No. 14, 7/4/34, pp. 436-438.) (8.252/29352 Germany.)

The authors propose that the compression for a two-stroke cycle engine be completed in a separate compressor driven by an auxiliary engine. The compressed air is exhaust-heated and supplied to the main engine at T.D.C. The old compression stroke becomes available for scavenging and no separate scavenge blower is required. It is claimed that this will enable the main engine to be coupled direct to the driving wheels of the locomotive. No details of the method of starting are given. (In this connection see Forschungsheft, No. 363, Abstract No. 28063, on the Deutz Diesel locomotive.)

Two references.

Deschamps 1,200 h.p. Diesel Aero Engine. (Flugsport, Vol. 26, No. 12, 13/6/34, pp. 249-250.) (8.252/29353 France.)

The engine has 12 cylinders in V of 6in. bore and 9in. stroke. It operates on the two-stroke cycle and is rated 1,200 h.p. at 1,600 r.p.m. for a weight of 2,400lb. Each cylinder is fitted with two injection pumps, operating during alternate cycles. In this way the pump speeds are halved and low speed engine operation is obtained by cutting out one pump and operating the engine on the four-stroke cycle.

Spark Plugs and Their Improvement. (H. Navratiel, Autom. Tech. Zeit., Vol. 37, No. 9, 10/5/34, pp. 238-240.) (8.283/29354 Germany.)

Attention is paid to the possible catalytic effect of the hot plug surface on the combustion. The aim should be to improve ionisation at the gap and reduce tendency to form carbon deposits on the plug. The author hopes to achieve this by suitable choice of insulation and electrode materials.

The Coal Dust Engine. (Dr. Ing. Wahl, W.R.H., Vol. 15, No. 14, 15/7/34, p. 200.) (8.290/29355 Germany.)

Coal dust engines are mainly of the injection type. The greatest difficulty is the rapid wear of cylinder liner and piston by abrasive material in the ash.

Special design of piston rings and grooves is required to prevent gas pressures from building up behind the rings. The pipe lines feeding the coal dust from the bunker to the injection valve must be designed to minimise the risk of premature explosions.

Steam Turbine for Aircraft. (O. R. Thomson, Luftwissen, Vol. 1, No. 4, 15/4/34, pp. 97-101.) (8.296/29356 Germany.)

The Huttner turbine works on the axial contrary flow principle, the steam nozzle rotating in the opposite direction to the blades. The nozzles are actually

the boiler elements and form a rotary boiler. Each element consists of a U-tube, one open end forming the steam nozzle, whilst the other open end takes in the water supply like a centrifugal pump. The hub attached to the steam nozzle is heated by blow pipe flame, the steam pressure generated depending on the pressure set up by centrifugal action on the water. Most of the exhaust steam is condensed by the inlet water and a relatively small condenser deals with the balance.

In the discussion following the lecture the heavy fuel consumption due to the absence of an exhaust vacuum is stressed. Mechanical difficulties are considerable. A model is stated to have given promising results.

Engines—Design and Strength of Components

Lubricated Journal Bearings with Dimensions of Roller Bearings. (A. Riebe, Z.V.D.I., Vol. 78, No. 14, 7/4/34, pp. 444-445.) (8.31/29357 Germany.)

A housing, clamped in the bearing, carries a press-fitted caro-bronze liner.

A hardened steel liner, locked on the shaft, runs in the caro-bronze liner. Lubricant is supplied by wick through the housing. The bearing surfaces may be cylindrical or have double curvature.

The steel liner can be unlocked from the shaft and the housing from the bearing, and the whole drawn out exactly like a ball bearing, a matter of importance for assembly and repair.

The selection of materials is stated to allow of loads equalling or exceeding those permissible on ball bearings of equal dimensions. The cost is presumably much less. (See Abstract 28773.)

Three references.

Contribution to the Question of Cylinder Wear of Internal Combustion Engines. (W. Ostwald, Autom. Tech. Zeit., Vol. 37, No. 9, 10/5/34, pp. 246-247.) (8.32/29358 Germany.)

The researches of Ricardo and the Institution of Automobile Engineers are reviewed. As an alternative to the corrosion explanation, the possibility of the steam condensing in the cylinder walls at low temperatures and forming an emulsion with the oil is put forward. Such emulsion may not be capable of producing an adequate lubricating film.

Three references.

Torsional Oscillations of Engines with Cylinders in Line. (R. Grammel, Ing. Arch., Vol. 5, No. 2, April, 1934, pp. 83-91.) (8.36/29359 Germany.)

The usual recursion formula is obtained by a simplified method and applied to a variety of cases with additional rotating masses.

The frequency formulæ are established in simple forms with sufficient accuracy for design calculations. Further extended applications are indicated.

Two references.

Measurement of the Bending Oscillation of a Two-Bearing Crankshaft Running Under Power. (W. Riede, Autom. Tech. Zeit., Vol. 37, No. 14, 25/7/34, pp. 366-368.) (8.36/29360 Germany.)

The oscillations were recorded optically by reflecting a beam of light from a mirror attached to the free end of the shaft. Under inertia forces only, the bending moment had three maxima per revolution. The vibrations were modified by the explosive forces. The only feasible cure was the provision of an extra (central) bearing.

Theory of the Resonance Vibration Damper. (L. Geislinger, Ing. Arch., Vol. 5, No. 2, April, 1934, pp. 146-155.) (8.36/29361 Germany.)

The mass of a vibration damper working on the resonance principle need only be 2 per cent. of the mass of the damped system or less if the timing is accurate.

The mathematical investigation shows that bad tuning of the damper is less harmful in defect than in excess of the natural period of the damped system.

Eight references.

Progress in Design of Air Engine Bearings. (A. Füssenhauser, Luftwissen, Vol. 1, No. 6, 15/6/34, pp. 158-161.) (8.37/29362 Germany.)

Improvements in fuels allow increased supercharger pressures, imposing higher bearing pressures. A brief survey is given of the literature of bearing lubrication from 1930-1934.

The non-dimensional parameter, viscosity × r.p.m./bearing pressure is proportional to the resistance torque down to the value 2.1 with 1 kg. weight as unit of force.

(Transformed to c.g.s. units,

$$\mu\omega/p = 2.1 \times 9.81 \times 10^5/2\pi \times 60 = 8.2 \times 10^4.)$$

Below this value lubrication, in the ordinary sense, fails.

Recommendations are made for the selection of bearing metals, the design of bearings and the selection and application of lubricants.

Forty references.

Engines—Cooling

Heat Transmission to Pipes when Coated with Dew and Rime. (W. Piening, Z.V.D.I., Vol. 78, No. 26, 30/6/34, pp. 813-814.) (8.40/29363 Germany.)

The experimental pipe was filled with liquid CO_2. The rate of evaporation of CO_2 determined the heat transfer. At low temperatures the pipe became coated with a layer of rime surrounded on the outside by a layer of ice. From the thickness of these layers concordant values of the heat transfer were obtained.

It appears that the coefficient of heat transfer thus obtained is related in a simple manner to the coefficient for dry air, obtained in a previous paper.

Five references.

Cowling of Air-Cooled Engines. (S. Hesse, Luftwissen, Vol. 1, No. 6, 15/6/34, pp. 162-165.) (29364 Germany.)

A summary is given of work in U.S.A. and in this country.

Nineteen references.

Cowlings for Radial Engines. (M. Giqueaux, Pub. Sc. et Tech., No. 42, 1934.) (8.426/29365 France.)

Reference is made to early use of cowlings, and to the systematic investigations recently carried out in this country and U.S.A. A description is given of work done in France and dimension sketches give full details of the combinations of cowlings and baffle plates tested.

Ten photographs show air flow round various models rendered visible by smoke jets. The numerical results are tabulated and shown graphically.

The best result obtained was a reduction of the drag to about 11 per cent. of the uncowled model engine. The question of cooling is passed over.

Theory of Townend Ring. (G. Otten, J.R. Aer. Soc., Vol. 38, No. 287, Nov., 1934, pp. 885-935.) (8.426/29366 Great Britain.)

The velocity field in the neighbourhood of a gauze wire obstruction is discussed by the methods of Froude, the obstruction being considered as a negative

actuator. Aerofoils are placed above and below the gauze (in mirror image relation to the centre line) and give a two-dimensional analogue of the Townend ring. The reaction on the aerofoils is measured and the effective circulation is deduced from the lift on the circulation theory.

An elementary consequence is the possibility of an upstream component of reaction on the aerofoils for a small range of effective incidence. Further, the circulation field of the aerofoils reduces the effective velocity through the gauze and hence the loss of total head in the wake.

Apart from the empirical determination of the drag coefficient of the gauze and the lift and drag coefficient of the aerofoil, the analysis is developed as for a perfect fluid and the various expressions are worked out approximately in a comprehensive manner.

The two-dimensional theory thus developed is transformed conformally to the field round a circular sheet of gauze surrounded by an annular aerofoil and the corresponding analysis is developed.

Applications to a multi-cylinder engine surrounded by polygonal aerofoils are considered and corrections in relation to the ideal case are estimated.

Numerous test results are tabulated and shown.

Seven references.

Theory of Cooling Through Evaporation. (G. Ackermann, Ing. Arch., Vol. 5, No. 2, April, 1934, pp. 124-146.) (8.460/29367 Germany.)

Cooling water by evaporation is common practice in large power plants. Recently the method has been applied to steam locomotives. By having the air in direct contact with the water, the plant is simplified and the cooling rate increased, but there is loss of water carried away as vapour in the air. This loss can be kept within reasonable limits. The warm water flows in a thin film down the surface of vertical plates and is met by an upward current of cold air. The process is investigated mathematically and the correlation between the heat transfer coefficient and diffusion is developed. With a suitable temperature range the loss of water is less than 1 per cent. (Application to oil cooling might be of interest.)

Seventeen references.

Engines—Fuels

The German Oil Fields. (R. v. Zwerger, Z.V.D.I., Vol. 78, No. 17, 28/4/34, pp. 525-531.) (8.60/29368 Germany.)

Germany consumes two million tons of liquid fuel per year. The home production from all sources is about 600,000 tons, out of which oil wells account for 200,000 tons. The most important oil fields are near Hanover. There are minor fields in Thuringia, Bavaria and the upper Rhine basins. A grant of 5 million marks has been made for trial borings in new districts.

Twelve references.

Hydrogenation of Coal. (H. Koppers, W.R.H., Vol. 15, No. 9, 1/5/34, pp. 108-110.) (8.602/29369 Germany.)

Statistics are given of German imports and internal production of coal spirit and of fuel alcohol. Imports for 1930 were about 1,000,000 tons and internal production of all kinds of motor fuel about 500,000 tons.

Fuel Investigations—Paper Read at the Meeting of the German Society for Fuel Oil Research. (A. v. Philippovitch, Z.V.D.I., Vol. 78, No. 26, 30/6/34, p. 792.) (8.640/29370 Germany.)

The papers deal mainly with the testing of fuels. For carburettor fuels the C.F.R. method is employed. For heavy oils a special Diesel test engine has been designed, in which the ignition lag is measured electrically.

Three references.

Equilibrium Volatility of Motor Fuels. (O. C. Bridgeman, Bur. Stan. J. Res., Vol. 13, No. 1, July, 1934, pp. 53-109.) (8.640/29371 U.S.A.)

An approximate equation connects equilibrium volatility of commercial fuels with standard A.S.T.M. distillation curves.

Researches on the Constitution of Paraffins and Gas Oils. (E. Carrière and H. Bonnet, Pub. Sc. et Tech., No. 43, 1934.) (8.640/29372 France.)

In publication No. 7 methods are described for determining the constitution of petrols from physical data, density, viscosity and refractive index of the original fuel or its products. These methods are extended in the present paper to cover the heavier fuels. The difficulties of analysis increase with molecular complexity, but the above methods, applied to a mixture of cumene, cymene, naphthalene and diphenylmethane give satisfactory results, which are quoted.

The Thermal Properties of Benzene/Air and Methyl Alcohol/Air Mixture. (J. Small, Phil. Mag., Vol. 18, No. 120, Oct., 1934, pp. 554-560.) (8.640/29373 Great Britain.)

The total heat of the fuel mixture is plotted against mixture strength for various temperatures and pressures, from the data given in the International critical tables.

In a complete combustion mixture of benzene/air there is no separation of fuel at atmospheric pressure for a temperature range extending below 30°C. With a complete combustion mixture of methyl alcohol/air, initially at 15°C., the air has to be preheated to 200°C. to ensure complete vapourisation.

Three references.

Fuels for Aero Engines. (E. L. Bass, Airc. Eng., Vol. 6, No. 70, Dec., 1934, pp. 320-325.) (8.645/29374 Great Britain.)

A review is given of the methods of measurement and relative importance of anti-knock rating, boiling point and vapour pressure. At present high anti-knock rating is the principal requirement and correlation between laboratory and full-scale experiments is needed. An easy method of detecting early stages of detonation in flight is especially required. The appearance of black smoke in the exhaust or abnormal temperature rise of the cylinder is not sufficiently sensitive.

Three references.

Causes of Detonation in Petrol and Diesel Engines. (G. D. Boerlage and W. J. D. Van Dyck, J.R. Aer. Soc., Vol. 38, No. 288, Dec., 1934, pp. 953-986.) (8.645/29375 Great Britain.)

In the petrol engine detonation is caused by the sudden inflammation of the " end gas " left unburnt after the greater part of the charge has been ignited by normal flame propagation. In the Diesel engine detonation is caused by sudden inflammation of the charge present in the cylinder at the conclusion of the " delay period." In each case part of the charge has become " activated " by reason of its previous history in the engine.

The authors take the view that the activation is primarily due to the presence of cracked fuel products, together with unstable oxygen molecules (not to be confused with so-called fuel peroxides, which only play a secondary part).

Defining ignition lag in reference to adiabatic compression under specified conditions, a small lag is desirable in an ignition engine, while a large lag renders detonation more difficult in the petrol engine. The authors have established a method of rating Diesel fuels in terms of cetene numbers. This number denotes the volumetric percentage of cetene in a mixture of cetene and methylnaphthalene which has the same ignition lag as the fuel. A high cetene number denotes a

good fuel with short ignition lag. In the case of the petrol engine a different method of rating, based on the suddenness of the explosion, has been in use for some time. Here a high octane number denotes a smooth running engine. If in each case ignition lag is the principal factor cetene and octane numbers should be related. The authors establish this relationship for a series of fuels and further demonstrate that both numbers are related to the reaction constant with which the fuel undergoes cracking.

Thirteen references.

The Causes of Detonation in the Carburettor and Injection Engine. (O. Holfelder, Z.V.D.I., Vol. 78, No. 27, 7/7/34, pp. 836-837.) (8.645/29376 Germany.)

This is a review of the work of Messrs. Boerlage and Van Dyck, reported fully in Abstract 29375.

True detonation is associated with gaseous vibration of the burning charge, knocking is due to mechanical vibration of the cylinder walls and " rough running " is due to crankshaft vibration. In each case auto-ignition takes place and disturbs smooth ignition by flame travel.

Four references.

Engines—Injection and Exhaust Systems

On the Effect of Pipe Bores on the Cut-off of Fuel Spray in Injection Systems with Open Nozzles. (F. Nakanishi, M. Ito and R. Kitamura, Aer. Research Institute, Tokyo, Report No. 108 (Vol. 8, No. 12), June, 1934.) (8.705/29377 Japan.)

The falling pressure/time curve of the oil in the pipe fluctuates about the mean slope for very low and very high oil speeds. Sharp cut-off is thus only possible over a range of pipe diameters.

Three references.

Silencing Arrangement for Aircraft Engines—French Patent No. 746961. (L'Aéron., No. 179 (Bulletin), April, 1934, p. 47.) (8.721/29378 France.)

Two exhaust valves, a smaller and a larger, are fitted. The small valve opens with the usual lead and closes about 40° A.B.D.C. The second, larger, valve then opens and discharges into atmosphere till the end of the stroke. It is claimed that a small silencer on the small valve is effective without serious loss of power.

Engines—Transmission

The Dynamics of the Differential Gear. (T. Pöschl, Z.V.D.I., Vol. 78, No. 26, 30/6/34, pp. 799-800.) (8.761/29379 Germany.)

The kinematics of differential gears in motor cars has been investigated more fully than the dynamics. The author develops energy equations, taking into account the inertia of the intermediate wheel.

In this case the pinion reactions on the left and right hand driving shafts are no longer equal.

Elastic Couplings in Torsional Oscillations. (V. Rembold and J. Jehlicka, F.G.I., Vol. 5, No. 3, May/June, 1934, pp. 146-154.) (8.765/29380 Germany.)

Sectional sketches show details of the four elastic couplings used and the general layout of the experiments. Characteristics of steel spring and rubber couplings are given in elaborate numerical tables and graphically, the area of the hysteresis loops being large in the rubber couplings.

An expression is given for the rate of loss of energy by damping.

Three references.

Behaviour of Threaded Connection on Tightening and Loosening. (E. Bock, Z.V.D.I., Vol. 78, No. 25, 23/6/34, pp. 780-781.) (8.769/29381 Germany.)

The experiments were carried out mostly on 1in. bolts and nuts. The loading reproduced practical conditions of hand tightening by 10in. spanner. Under these conditions the material is never dangerously strained, even if considerable tolerance is given to the accuracy of workmanship.

Four references.

Armament

Hispano-Suiza Large Calibre Machine Gun. (Flugsport, Vol. 26, No. 10, 16/5/34, pp. 210-211.) (9.11/29382 Germany.)

The calibre is 20 mm. The machine gun is mounted in the V of the engine and fires through a hollow airscrew shaft. The rate of fire of the cannon is stated to be equal to that of the machine gun. Explosive and tracer ammunition is used. The gun weighs 116lb., the magazine with 60 rounds weighs 55lb., total 171lb. Two additional machine guns of normal calibre fire through the airscrew disc.

Machine Gun Operation at High Altitude. German Patent No. 598251 (1932). (Flugsport, Vol. 26, No. 13, 27/6/34, pp. 85-86.) (9.11/29383 Germany.)

The operator in a pressure sealed chamber manipulates the machine gun, which is placed in the open. Troublesome pressure seals are thus avoided.

Improvements in Machine Gun Mounting in Aircraft. French Patent 718964. (K. G. Ostberg, Rev. de l'Armée de l'Air, No. 58, May, 1934, pp. 613-617.) (9.14/29384 France.)

An epicycloidal transmission gear transforms rotary motion of the engine into a rectilinear reciprocation which is applied to the interrupter gear.

History of Explosive Bullet in Aerial Combat. (P. Barjot, Rev. de l'Armée de l'Air, No. 59, June, 1934, pp. 687-700.) (9.15/29385 France.)

A description is given of English and German explosive, incendiary and tracer ammunition used in the late war. A light shell of this type has been developed, which would probably put any aircraft out of action by a single hit. On this account the author strongly recommends a reduction in the size of bombing aircraft to reduce the size of target.

Reference is made to the Madsen and Oerlikon machine guns, which handle ammunition of this type of 20 mm. calibre. The Oerlikon is a development of the Becker gun used by the Germans towards the end of the war.

Eight references.

Construction of a Firing Table for Bombs Dropped from Aircraft. (N. Cavicchioli and U. Ricca, L'Aerotecnica, Vol. 14, No. 6, June, 1934, p. 716.) (9.16/29386 Italy.)

A relation is obtained between a form coefficient and the observed time of fall from a kite balloon at known height.

Corrections for a Trajectory. (A. Wertheimer, J. Frank. Inst., Vol. 217, No. 6, June, 1934, pp. 729-742.) (9.16/29387 U.S.A.)

A method of computing trajectories was developed in F. R. Moulton's " New Methods in Exterior Ballistics," 1926.

The present paper gives a routine for calculating correction from Moulton's standard trajectories required by changes in initial conditions.

Approximate differential relations are developed and a numerical example is computed.

Vulnerability of Warship Structures. (H. Evers, W.R.H., Vol. 15, No. 11, 1/6/34, pp. 142-3, and No. 12, 8/6/34, pp. 163-164.) (9.53/29388 Germany.)

A fundamental distinction is drawn between the effect of shells and bombs hitting above water and under water. The latter resembles the effect of under water mines and torpedoes. Detonation in an enclosed space naturally increases the effect of the explosion.

Examples are given from research trials and from naval actions.

Seven references.

Calculating Machine for Directing Anti-Aircraft Fire. French Patent 706020. (P. Algrain, Rev. de l'Armée de l'Air, No. 58, May, 1934, pp. 608-613.) (9.61/29389 France.)

The altitudes and azimuths of an aircraft, observed continuously from two or more bases, are differentiated with respect to time by the mechanism, and their values, after a further time corresponding to the time of flight of the projectile, are given by extrapolation of the aircraft's trajectory.

The mechanism is necessarily somewhat complicated.

Estoppey Bomb Sight. French Patent. (P. Léglise, Rev. de l'Armée de l'Air, No. 59, June, 1934, pp. 713-736.) (9.62/29390 France.)

This bomb sight (Type D.4) is in use by the American authorities. A specimen sight has been purchased by the French Government. The article gives a full illustrated review of the French covering patent.

Materials—Characteristics, Defects and Treatment

Brinell Hardness of Bearing Metals. (A. Väth, Z. Metallk., Vol. 26, No. 4, April, 1934, pp. 83-86.) (10.101/29391 Germany.)

Tables are given correlating the hardness figure with the load and time of contact. In testing bearing metals the load and time should be adjusted so that the diameter of the impression is about half the diameter of the ball.

Five references.

Stainless Steel. (F. Flader, Trans. A.S.M.E., Vol. 56, No. 5, May, 1934, pp. 295-300.) (10.102/29392 U.S.A.)

A particular specification is recommended as suitable for U.S.A. aircraft construction and the strain-stress characteristic is shown graphically. Its general behaviour, during manufacturing processes and in service, is discussed.

Comparison is made with aluminium alloys and the final recommendation gives preference to stainless steel on the ground of rate of production, welding properties, treatment, cost, etc.

Photographs show examples of welds and a micro-photograph shows a section of one of the welds.

The Internal Mechanism of Metals. (W. Kuntze, Z. Metallk., Vol. 26, No. 5, May, 1934, pp. 106-112.) (10.104/29393 Germany.)

The behaviour of a substance under deformation is largely determined by internal molecular cohesion and resistance to slip. The field of stress in a body is affected by heterogeneity and local peaks of stress may produce slip in a metal before general flow sets in. A minute slip will generally produce a new configuration of greater inherent strength. There is a momentary stiffening up of the material, to be followed by a further slip if the load is increased. This accounts for the " crackling " noise emitted by many metals under tensile tests.

In the case of certain light alloys under tensile tests, the vibration of the loading line is well marked, although noise is generally absent. A substance will

fail under fatigue sooner than under static load, since there is no time for internal rearrangement producing local stiffening.

The article is illustrated by wood models demonstrating the mechanism of cohesion and slip.

Twenty-three references.

Cold Press Test of Sheet Metals. (H. Fournier, Pub. Sc. et Tech., No. 44, 1934.) (10.104/29394 France.)

The sheet under test is clamped between annular plates and a die presses the free metal into a dish form. Two variants are used, in one of which the metal sheet is bored centrally, in the other is left intact.

The load of final rupture is taken as the test figure. The first method is standardised in Germany and in either form the test is considered by the author as entitled to high consideration by reason of the uniformity of results.

Extensive tables of test figures by both methods are given, with tensile strength and elongation test figures for comparison. Photographs show examples of the dished form produced during test and microphotographs show the grain of various specimens.

Seven references.

Strength Calculation of Vehicle Axles. (A. Thum and F. Wunderlich, Z.V.D.I., Vol. 78, No. 27, 7/7/34, pp. 823-824.) (10.104/29395 Germany.)

Axles may fail under fatigue or under shock. In rail car construction the temperature of the axle is important. Surface treatment by pressing, polishing or hardening extends the fatigue limits.

Eleven references.

Fatigue Limits and Notch Tests of Steels at Low Temperatures. (H. Wontrup, Z.V.D.I., Vol. 78, No. 18, 5/5/34, p. 565.) (10.104/29396 Germany.)

A reduction in temperature to $-20°$C. increases the fatigue limits of crankshaft and chrome nickel steels about 10 per cent. Ultimate tensile is also increased, but the resistance to notch impact is sensibly reduced.

Three references.

Recent Development of Permanent Magnet Steels. (W. Steinhaus and A. Kussman, Phys. Zeit., Vol. 35, No. 9, 1/5/34, pp. 377-382.) (10.105/29397 Germany.)

The recent development of permanent magnet steels is based on the relation between heterogeneity of chrystalline structure associated with internal stresses. The metallurgical physical problem is discussed briefly.

A graphical chart shows the properties of two Fe. Co. Mo. magnet steels quenched at 1,300° and annealed at 700°, showing a residual magnetic indication of 10,000 C.G.S. units and a coercive force of 300 gauss.

The change in micro-structure on annealing is shown by microphotographs. A chart and table show in comparative form the properties of seven modern magnet steels.

Twelve references.

The Recovery of Metals from the Results of Cold Working. (G. Tammann, Z. Metallk., Vol. 26, No. 5, May, 1934, pp. 97-105.) (10.12/29398 Germany.)

When metals are cold worked many properties, such as electrical resistance, thermo-E.M.F., etc., are changed concomitantly with the mechanical properties. A subsequent heat treatment will generally restore the metal to its original condition.

The minimum temperature rise required varies for different properties. The change of electrical resistance with temperature is especially sensitive and, from the type of recovery curve obtained, the author suggests that the process of cold working modifies the individual metallic molecules very unevenly. Maximum temperature effect occurs when the largest number of atoms returns to the normal condition.

Twenty-five references.

Temperature Recording Paints. (Airc. Eng., Vol. 6, No. 69, Nov., 1934, p. 305.) (10.12/29399 Great Britain.)

The colour changes of recording paints containing metallic iodides are not reliable under prolonged heating and cooling. Mixtures of clays and metallic oxides behave more consistently, but further research is required.

An Accelerated Nitriding Process. (Autom. Tech. Zeit., Vol. 37, No. 14, 25/7/34, p. 372.) (10.12/29400 Germany.)

The usual nitriding process requires about 16 hours in an atmosphere of NH_3 at temperatures between 460-580°C. Both time and temperature are reduced considerably by gaseous accelerators—pyridine, nitric oxide, etc.

A covering of copper gauze over the part to be nitrided reduced the time to four hours at 460°C.

Corrosion of Ferrous Metals in Acid Soils. (I. A. Denison and R. B. Hobbs, Bur. Stan. J. Res., Vol. 13, No. 1, July, 1934, pp. 125-150.) (10.125/29401 U.S.A.)

Correlations were obtained between acidity of soil and rate of pitting, under both practical and laboratory conditions.

Photographs show corrosion on pipe lines in soil and on discs in laboratory tests.

Tables of numerical data are given for thirty soils.

Eighteen references.

Durability of Protective Coatings on Steel. (M. Komers, Z.V.D.I., Vol. 78, No. 26, 30/6/34, p. 813.) (10.125/29402 Germany.)

The effectiveness of the coating depends on the composition of the steel and its surface treatment prior to painting. Burnishing with oil or a mixture of oil and red lead is very effective and accounts for the well-known resistance shown by old iron work made by the puddling process.

Three references.

Aluminium Alloys as Piston Material. (R. Sterner-Rainer, Z. Metallk., Vol. 26, No. 6, June, 1934, pp. 141-142.) (10.231/29403 Germany.)

Aluminium silicon alloys, with their low coefficient of expansion and good wearing properties, are receiving increasing attention as piston material, since improvements in casting technique have reduced the grain of any silicon which comes out of solution.

Alloy pistons are suitable for high speed steam engines, but have received limited application so far.

Tests on Duralplatt. (K. L. Meissner, W.R.H., Vol. 15, No. 9, 1/5/34, pp. 107-108.) (10.231/29404 Germany.)

A descriptive summary is given of the patent situation with brief reference to tests in comparison with magnesium alloys.

Light Alloy Rivets. (K. Guler, Z. Metallk., Vol. 26, No. 4, April, 1934, pp. 90-91.) (10.29/29405 Germany.)

Details are given of manufacture and of testing. The effect of heat treatment and temperature control on the subsequent age hardening is fundamental.

Safety Glass for Vehicles. (M. Heckter, Z.V.D.I., Vol. 78, No. 24, 16/6/34, pp. 757-758.) (10.406/29406 Germany.)

Most of the safety glass in use consists of two thin sheets of plate glass which are held together with some transparent cement. This cement may be derived from

(1) Celluloid.
(2) Cellon.
(3) Certain condensation and polymerisation products of organic esters.

The celluloid cements at present are the cheapest and in most general use. The cements of groups (3) are more stable than those of groups (1) and (2) as judged by discolouration and patches, but are affected more adversely by heat and cold.

Three references.

Extending the Life of Wooden Masts. (W. Mühlan, Z.V.D.I., Vol. 78, No. 14, 7/4/34, pp. 434-436.) (10.420/29407 Germany.)

Wooden masts chemically treated rot near the ground after about eight years, whilst the rest of the mast is still comparatively sound. In the new methods here described chemically treated pads are wrapped round the vulnerable parts of the mast. Differences in osmotic pressure cause the salts to impregnate the wood and prolong the life of the mast. A saving of between one and two marks per mast is claimed.

Three references.

Grain of Coats of Paint. (W. Toeldte, F.G.I., Vol. 5, No. 3, May/June, 1934, pp. 121-126.) (10.603/29408 Germany.)

Fourteen photographs are reproduced and show the surface formation and sections of protective coats. Specifications are given of the varnishes and solvents and methods of application are discussed in a practical manner.

Testing Apparatus and Methods of Testing

Turin Aeronautical Laboratory. (L'Aerotecnica, Vol. 14, No. 4, April, 1934, pp. 359-434.) (11.10/29409 Italy.)

A description is given of the mounting of aerofoils, etc., on wire suspensions and the reduction of the readings to force and moments impressed. Airscrews are mounted on a torsion balance, the details of which are shown in a section sketch.

Numerous examples of experimental work are described and international comparisons are given. Numerical results are given graphically in fifty diagrams.

Twelve references.

The Froude Tank of the Hydrodynamical Laboratory of the Italian Ministry of Aeronautics. (L'Aerotecnica, Vol. 12, No. 4, April, 1932, pp. 447-472.) (11.20/29410 Italy.)

The dimensions are given in sketches and the more important items of equipment in sketches and photographs. The total length is 176 metres, depth 2.3 metres, width 3 metres. The maximum velocity of the travelling carriage is 10 m./s.

There are two small subsidiary tanks with continuous flow, maintained by a circulation pump absorbing 25 h.p. Typical curves of air and water resistance of a hull are reproduced and a combined diagram of characteristics is constructed in non-dimensional co-ordinates.

Tank Experiments on Model Seaplane Floats (1st Series)—Directorate of Research and Experiment, Ministry of Aeronautics, Report No. 3. (A. Eula, L'Aerotecnica, Vol. 14, Nos. 8-9, 1934, pp. 947-990.) (11.20/29411 Italy.)

(The equipment of the laboratory was described in L'Aerotecnica, April, 1932. See Abstract 29410.)

Measurements were made with 17 models, eight of type A, six of type B, two of type C, one of type D. The float lift, trim angle, resistance/total lift, and resistance/float lift, are plotted in non-dimensional co-ordinates, formed on the basis of Froude's theory.

The float lines and dimensions are given in separate diagrams. The departures of the principal dimensions, *e.g.*, length of beam, from geometrical similitude are within moderate ranges and are shown in a table.

Approximate numerical values may be taken from the curves for any hull or float design not departing much from the nearest type in the present series.

100th Report of the Hamburg Naval Research Institute—Model Measurements in a Current of Water. (K. Holm, W.R.H., Vol. 15, No. 12, 8/6/34, pp. 146-148.) (11.20/29412 Germany.)

The level in the service tanks is 1.5 metres higher than the mean channel level and the sink tank 0.5 metres lower. A delivery of 900 cub. metres per hour is available for nearly three minutes, with a maximum current of 0.25 m. per sec. Measurements of resistance power and efficiency, trim angle and steerability are transformed to full-scale in open water and in a channel 3 m. deep × 37.7 m. wide for relative speeds from 7 to 17 km./hrs. and for currents zero and ±7 km./hrs. There is a correction of −2 per cent. to −4 per cent. from model to full-scale in the required power. Detailed consideration is given to numerous factors affecting dynamical similitude.

In Report 113, which follows immediately, a full technical description is given of the installation.

The Resistance of a Ship in a Channel. (Dr. J. Kreitner, W.R.H., Vol. 15, No. 7, 1/4/34, pp. 77-82.) (11.22/29413 Germany.)

The velocity field near the hull is modified by the constriction of the channel by the hull itself and the characteristic velocity of waves is modified by the depth of water. Expressions for these well-known effects are written down and discussed numerically.

The computed values are compared with measurements in graphical form and show satisfactory agreement.

Three references.

Static Wing Rib Tests. (A. W. Clegg, Airc. Eng., Vol. 6, No. 69, Nov., 1934, pp. 301-302.) (11.32/29414 Great Britain.)

The labour of calculating the correct load distribution at 16 or more stations along the chord is much reduced by the use of sixteen typical curves of percentage partial loads, one at each station, plotted against the fraction of the chord defining the centre of pressure.

Physical Relation between the X-Ray Unit and the Radium Unit. (R. Jaeger, Phys. Zeit., Vol. 35, No. 7, 1/4/34, pp. 273-275.) (11.47/29415 Germany.)

The definition of international unit of X-ray radiation is based on the production of unit electrostatic change in an ionisation chamber. The unit is called the

Röntgen. The radium unit is based on the intensity of radiation from 1 milligramme of radium at 1 centimetre from the radium preparation. Both may be reduced to a count of electrons and by this method the numerical ratio is approximately :—

1 radium unit = 7.35 Röntgen units.

Fourteen references.

Relation between Thermal and Mechanical Rupture of Molecular Bonds. (F. Regler, Ann. d. Phys., Vol. 19, No. 6, April, 1934, pp. 637-664.) (11.47/29416 Germany.)

X-rays, refracted by the molecular structure, exhibit characteristic interference lines. These lines broaden under mechanical stresses and under temperature increase. A maximum breadth is observed just before yield or rupture and corresponds to a maximum absorbable strain energy. The same broadening effect under increase of temperature and the same maximum value precedes melting.

The author's method of obtaining photographic records is described and four photographs are reproduced. The numerical results are exhibited graphically.

Twelve references.

Optical Indicator. (J. Sci. Inst., Vol. 11, No. 12, Dec., 1934, pp. 396-399.) (11.55/29417 Great Britain.)

In this new form of the Perry indicator the deflection of the diaphragm is measured by the tilt of a mirror fastened to it. A reciprocating stroke mechanism operating with steel tape and rollers is provided.

Magnetic Pressure Indicator for Internal Combustion Engines. (T. Kobayasi and S. Sakuma, Aer. Res. Institute, Tokyo, Report No. 109 (Vol. 9, No. 1), July, 1934.) (11.55/29418 Japan.)

Authors' Abstract.—The applications of the inverse Wiedemann effect to torque measurements and to torque variation recordings were devised by the writer and the details of the experiments were published in the Reports, Vol. 4, No. 52, and Vol. 5, No. 54. If a ferro-magnetic bar is furnished with a twisting arm, a force, or variations of a force, can be measured in the same way. The writer constructed a pressure indicator for an internal combustion engine and obtained satisfactory results.

The Isotta-Fraschini High Altitude Test House for Aero Engines. (O. Kurtz, Luftwissen, Vol. 1, No. 5, 15/5/34, pp. 135-138.) (11.55/29419 Germany.)

The plant is designed to deal with water-cooled engines up to 800 h.p. under altitude conditions corresponding to 33,000 feet (0.26 atmospheres absolute, -50°C. intake temperature). During the test the engine is exposed to a stream of air at low temperature and pressure to reproduce actual cooling conditions. The air is circulated at about 60 m.p.h. and brine cooling keeps the temperature down to -18°C.

(In the American and English plant the external surface of the engine is kept under normal atmospheric conditions in still air.) The combustion air is drawn from the channel and undergoes a second cooling (down to -50°C.) before it enters the engine. A turbo pump removes the engine exhaust and any leakage air and maintains the low pressure in the channel. To make good the air consumption of the engine fresh air is drawn from the external atmosphere and is cooled before it enters the channel.

The engine power is measured by a water brake situated outside the channel. The power consumption of the test house includes 160 h.p. for the NH^3 cooling

plant of 250,000 cal./h. capacity and 60 h.p. for the wind channel (70 m. 3/sec. at 0.26 atmospheres and $-18°$C.).

A considerable extension of the plant will be necessary before it can deal with air-cooled engines.

Four references.

High Altitude Tests of Aero Engines. (P. Ragazzi and F. Righetti, Riv. Aeron., Vol. 10, No. 5, May, 1934, pp. 268-325.) (11.55/29420 Italy.)

High altitude tests in flight are restricted by lack of consistent and reliable instruments for measuring power. Tests on mountains are restricted in altitude and temperature.

The authors describe fully the Fiat Italian high altitude test plant, which resembles in some respects the Isotta-Fraschini installation. (See Abstract 29419.) The whole engine is placed in a low density high speed air current at low temperature, with a closer approach to flight conditions. The whole cooling of air-cooled engines is effected by the air stream and this limits the test range to 500 h.p. at 15,000 feet.

With water-cooled engines, the jacket cooling can be effected by radiators outside the air stream and the test range is extended to 500 h.p. at 30,000 feet.

Precautions against explosion are described.

Fifteen references.

Airships and Balloons

Disaster to Russian Stratosphere Balloon. (Luftwissen, Vol. 1, No. 4, 15/4/34, p. 105.) (12.0/29421 Germany.)

According to Russian accounts the disaster was due to insufficient ballast reserve for the prolonged stay at high altitudes. At sunset the rapid cooling of the gas reduced the residual lift so far (presumably below the net weight without ballast) that a catastrophic fall resulted.

Design of Rigid Airships. (K. Arnstein, Trans. A.S.M.E., Vol. 56, No. 6, June, 1934, pp. 385-392.) (12.10/29422 U.S.A.)

The author is in charge of the engineering activities of the Goodyear Zeppelin Corporation.

The weight analysis of various types is considered and some comparative figures are tabulated. The importance of power plant output per unit weight is referred to, and the overweight of the R.101 is attributed to the high specific weight of the Diesel engines.

Frame design and stress calculations are briefly discussed, and a photograph shows a model frame section under static test. Performance is discussed as a function of useful load, fuel consumption, drag and speed.

Six references.

Airship Performance. (G. Fulton, Trans. A.S.M.E., Vol. 56, No. 5, May, 1934, pp. 301-303.) (12.30/29423 U.S.A.)

Methods of improving performance of airships as long range carriers are discussed in general terms, which include water recovery as ballast, power plant improvements, use of excess hydrogen as fuel, and fire hazards, with the inevitable comparison of the advantages and disadvantages of helium.

Wireless

Microphone Noise in Vacuum Tubes. (D. P. Penick, Bell Tele. B-814, 1934.) (13.2/29424 U.S.A.)

Measurements of microphonic noise level are shown graphically. Methods of reducing noise are discussed and recommendations are made.

Seven references.

Fluctuation Noise in Vacuum Tubes. (G. L. Pearson, Bell Tele. B-813, 1934.) (13.2/29425 U.S.A.)

Sources of fluctuating noise are enumerated and their relative magnitude indicated.

Quantitative measurements in typical tubes are tabulated and recommendations are given.

Nineteen references.

Extension of Theory of Three-Electrode Vacuum Tube Circuits. (S. A. Levin and L. C. Peterson, Bell Tele. B-812, 1934.) (13.2/29426 U.S.A.)

The effects of feed-back between input and output circuits is considered to second and higher approximations, on the assumption that the amplification factor is constant and that the conductive grid current is zero.

The analysis is in terms of complex algebra and illustrative numerical constants are given.

Seven references.

Resistance Tuning. (S. Cabot, Proc. Inst. Rad. Eng., Vol. 22, No. 6, June, 1934, pp. 709-731.) (13.2/29427 U.S.A.)

The theory of resistance and reactance tuning is discussed mathematically. The variation in amplification by the latter may be as high as 10 to 1, while resistance tuning keeps the variation within practicable limits, about 3 to 1.

Five references.

Distributed Capacity of Single Layer Coils. (A. J. Palermo, Proc. Inst. Rad. Eng., Vol. 22, No. 7, July, 1934, pp. 897-905.) (13.2/29428 U.S.A.)

Previous experiment and theory are in disagreement, which is largely removed by introducing two new parameters, the diameter of the conductor and the pitch of the windings, the ratio of which affects the capacity sensibly.

Nine references.

Suppression of Interlocking in Detector Circuits. (P. W. Klipsch, Proc. Inst. Rad. Eng., Vol. 22, No. 6, June, 1934, pp. 699-708.) (13.2/29429 U.S.A.)

The pentagrid converter has solved many problems, but may be subject to excessive interlocking with short waves or high frequency beats.

A modification of the usual circuit was devised which reduced the forced change in frequency from 0.15 per cent. to 0.005 per cent. Modifications of the tube construction are discussed with the same object.

Three references.

Free Oscillations of a Condenser Circuit with a Periodically Variable Capacity. (A. Erdelyi, Ann. d. Phys., Vol. 19, No. 6, April, 1934, pp. 585-622.) (13.2/29430 Germany.)

The problem arises in telephone circuits where the sound vibrations produce modulations in the capacity.

A differential equation of Hill's type is found and discussed by various methods for stable and unstable conditions. The solutions, involving elementary transcendentals, Bessel and Neumann functions, etc., are not susceptible of abstracting.

Nineteen references.

Influence of Stray Capacitance on Antenna Measurements. (E. A. Laport, Proc. Inst. Rad. Eng., Vol. 22, No. 5, May, 1934, pp. 657-669.) (13.2/29431 U.S.A.)

Diagrams of circuits are shown for typical cases and the corresponding vector diagrams of voltage and current are drawn, giving numerical values which agree with measurement.

High Frequency Models in Antenna Investigation. (G. H. Brown and R. King, Proc. Inst. Rad. Eng., Vol. 22, No. 4, April, 1934, pp. 457-480.) (13.2/29432 U.S.A.)

The feasibility is considered of setting up of models with sufficient approach to electro-magnetic similitude with full-scale work.

Most of the paper is given to discussion of distortion by wireless masts or towers in resonance with the field. A guarded conclusion is given that the method may be useful as a check on the assumption underlying theoretical developments and in suggesting generalisation of theory.

Nine references.

Frequency Transformations by Rectifier with Capacity Load. (J. Kluge, Phys. Zeit., Vol. 35, No. 7, 1/4/34, pp. 275-278.) (13.2/29433 Germany.)

Diagrams show the fundamental elements of a rectifier circuit with capacity load and the complete installation discussed in the present paper. The products of large values of the resistance and capacity give a large time of decay, which maintains a voltage superposed on the rectified voltage.

A diagram shows the superposed voltage maintained over four peaks of the rectifier voltage at a sufficient level to prevent sparking.

Oscillograph records for specified values of capacity, resistance, reactance, etc., show 2 : 1 and 4 : 1 transformations. Specifications are given for applications to marking time intervals and to illumination of lamps for stroboscopic observations.

Two references.

Practical Measurement of Degree of Amplitude Modulation. (L. F. Gaudenack, Proc. Inst. Rad. Eng., Vol. 22, No. 7, July, 1934, pp. 819-846.) (13.2/29434 U.S.A.)

A critical review of existing methods is given. The requirements for a direct reading modulation are specified and an instrument designed on these lines is shown in photographs. Two diagrams of connections and calibration curves for three ranges are given.

Sixteen references.

Echoes of Radio Waves. (N. Janco, Proc. Inst. Rad. Eng., Vol. 22, No. 7, July, 1934, pp. 923-925.) (13.30/29435 U.S.A.)

Ordinary waves may have right-handed polarisation or left-handed polarisation. The former may penetrate the E layer of ionisation and undergo repeated reflections between E and F layers, with final escape through gaps in the E layer which would account for long delay echoes and suggests that they occur more frequently than actual observation records.

Six references.

Echoes from the Ionisphere. (L. C. Verman, S. T. Char and A. Mohammed, Proc. Inst. Rad. Eng., Vol. 22, No. 7, July, 1934, pp. 906-922.) (13.30/29436 U.S.A.)

A description is given of apparatus for making film records of time and intensity of reflected impulses. Repeated reflections between E and F layers account for long retardation.

Twenty-seven references.

High Quality Radio Broadcasting. (S. Ballantine, Proc. Inst. Rad. Eng., Vol. 22, No. 5, May, 1934, pp. 564-629.) (13.31/29437 U.S.A.)

A comprehensive review is given of the underlying problems. The wave band separation of stations is 10 kc. and the range of modulation frequencies

required is about 8 kc. for orchestral music. This produces an overlap of side bands by 3 kc. which sets up chattering.

Disc microphone characteristics are shown as functions of incidence, frequency and temperature. To eliminate the incidence effect a crystal piezo electric has been designed with cylindrical symmetry, about a vertical axis, so that the reception from sources of sound grouped round it are uniformly effective. Volume control, antenna characteristics and ground effect are discussed.

Thirty-six references.

League of Nations Wireless Station. (G. F. Van Dissel, Proc. Inst. Rad. Eng., Vol. 22, No. 4, April, 1934, pp. 430-448.) (13.31/29438 U.S.A.)

An account is given of the political compromise whereby a wireless transmitting station is available for international announcements by the League.

A descriptive technical account is given of the equipment of the station, which began partial operations in 1932.

Wireless Equipment on Federal Airways System, U.S.A. (L'Aéron., No. 181, June, 1934, pp. 141-142.) (13.30/29439 France.)

A general description of the system is given and a journey from Cleveland to Chicago entirely by wireless soundings is described in detail.

Wireless Beacons on the U.S.A. Air Lines. ((L'Aéron., No. 181, June, 1934, p. 137.) (13.4/29440 France.)

The article describes the experiences of and gives an entirely favourable account by a French pilot who used the system over the transcontinental route.

Gliding-in Beacons. (C. Jung-Zaeper and E. Kramar, Luftwissen, Vol. 1, No. 4, 15/4/34, pp. 92-95.) (13.4/13.6/29441 Germany.)

In the well-known American method of Diamond and Dunmore, a long wave beacon gives distant direction and the gliding-in course is directed by short waves from a complicated system of antennæ.

The German method patented by Lorenz, directs both distance and gliding courses by signals from a simple short wave framework. The method is awaiting trials.

Seven references.

Blind Landing by Means of Electrical Devices. (P. Handel, Luftwissen, Vol. 1, No. 7, 15/7/34, pp. 186-189.) (13.4/29442 Germany.)

The D.V.L., in conjunction with Messrs. Lorenz, have developed a polarised radio beacon system suitable both for horizontal and vertical navigation. The wave length is of the order of 9 metres and a special antenna of low air resistance has been developed for fitting to the aircraft.

Six references.

Landing in Fog. (R. Stüssel, J.R. Aer. Soc., Vol. 38, No. 286, Oct., 1934, pp. 807-836.) (13.4/29443 Great Britain.)

A descriptive technical account is given of the wireless beacon system used by Luft Hansa, and of the required aeroplane equipment, the latter weighing 8 kg. Photographs and diagrams of connections exhibit the details. A typical landing is described.

Statistics are given of the numbers of bearings given in Luft Hansa operations, increasing from 1,610 in 1929 to 32,500 in 1933. Failures to maintain night services show heavy seasonal increases in mid-winter and successful landings show a corresponding increase in the occasions when the beacon system was required.

Reference is made to short wave developments (9 metres), but the problem is not yet fully solved and further research and development is required. The discussion brought out a wide range of experiences and opinions relating to work in this country.

Problem of "Bad Weather" Landing of Aeroplanes. (R. Stüssel, Luftwissen, Vol. 1, No. 5, 15/5/34, pp. 128-134.) (13.4/29444 Germany.)

Bad weather flying through a limited zone, in particular bad weather starts from an aerodrome, are made reasonably safe by reliable instruments which have been evolved for "blind flying." Bad weather landings require special instruments, both on the ground and in the machine. Progress has been made in landings on aerodromes where a ground organisation is available.

The direction of flight and the horizontal distance from the landing ground are generally obtainable by wireless methods, the apparatus described here conforming closely to American practice. Height above ground is generally estimated by some type of static pressure gauge which, though imperfect, is more practicable than wireless transmission of instantaneous distance and direction. The concentrated efforts of specialist firms have not yet solved these instrumental problems.

Forced landings in bad weather in unknown territory, where the pilot can rely only on his own instruments, still involve serious risks.

Compensation of Distortion by Space Charge in Gas-Filled Cathode Ray Oscillograph Tubes. (M. v. Ardenne, Proc. Inst. Rad. Eng., Vol. 22, No. 4, April, 1934, pp. 423-429.) (13.5/29445 U.S.A.)

The non-linear characteristic of an uncompensated tube is shown by oscillograph records. The use of the linear part of the characteristic by bias on the deflecting plate involves either restoration of symmetry by an independent magnetic field or the use of asymmetrical tubes with attendant difficulties of manufacture.

In the present paper a method is described in which one or both of the deflecting plates is divided and equal and opposite bias voltages are applied to both parts. Two pairs of deflecting plates, the pairs being mutually at right angles, are employed. The beam passes the pairs of plates successively and the final direction of the cathode ray after the two successive deflections is axial.

Records are shown of a distorted sine curve and of the pure sine wave obtained by this method of correction.

Four references.

Seventy-five Centimetre Radio Communication Tests. (W. D. Hershberger, Proc. Inst. Rad. Eng., Vol. 22, No. 7, July, 1934, pp. 870-877.) (13.6/29446 U.S.A.)

The sender was 200 feet above sea level, the receiver 20 feet above sea level, giving a straight line range of 16½ miles tangent to the earth's surface. Telephonic communication was good up to 20 miles and telegraphic communication up to 88 miles, about five times the horizon range.

Nine references.

Maintaining Directivity of Antenna Arrays. (F. G. Kear, Proc. Inst. Rad. Eng., Vol. 22, No. 7, July, 1934, pp. 847-869.) (13.6/29447 U.S.A.)

Slight changes in phase and magnitude of the antenna currents seriously alter the directional intensity.

Constancy of line current ratios is obtained by building out the transmission lines to 90° in parallel or 180° in series. Numerical characteristics of the current lines are given and the circuits are shown diagrammatically. The theory is

worked out mathematically and the characteristics shown graphically. The system has been applied successfully.

Five references.

Ultra Short Wave Generators. (E. W. B. Gill, Phil. Mag., Vol. 18, No. 121, Nov., 1934, pp. 832-838.) (13.6/29448 Great Britain.)

In the usual arrangement the Lecher wires are connected to anode and grid and to extension plates. In an alternative arrangement the wire attached to the grid is split, the two ends connected to the filament, and two to a split condenser plate. In this arrangement the oscillations are maintained by the current to the anode alone.

It appears that the assumption of damping by the anode current and of independent internal oscillations in the valve are untenable.

Six references.

Television with Cathode Ray Tubes. (V. K. Zworykin, H.F. Technik, Vol. 43, No. 4, April, 1934, pp. 109-121.) (13.7/29449 Germany.)

A detailed description is given of operation with the instruments known as the " Ikonoscope " and the " Kinescope." (See Abstract No. 28848.)

Ten references.

Theory of Scanning. (P. Mertz and F. Gray, Bell Tele. B-799, 1934.) (13.7/29450 U.S.A.)

Blurring is due to the discrete division of the field and extraneous patterns are due to the original and scanning system. Extraneous patterns can be eliminated at the cost of increased blurring.

A comprehensive Fourier analysis of intensity distribution along the frequency spectrum is worked out, Bessel functions of both kinds and of various orders appearing in the analysis. The results are exhibited graphically.

Constancy of Selenium Layer Photocells. (L. Bergmann, Phys. Zeit., Vol. 35, No. 11, 1/6/34, pp. 450-452.) (13.7/29451 Germany.)

The characteristics of four cells are given in numerical tables. Provided that the cells are not overloaded they maintain a reasonably constant characteristic for over 100 hours of continuous load.

Photography

Cinematograph Record of Aeroplane Motions During Start. (W. Pleines, L.F.F., Vol. 11, No. 1, 15/5/34, pp. 16-25. D.V.L. Report, No. 33/03.) (14.28/29452 Germany.)

A sketch shows the position of a cinematograph camera on the ground; the region of observation was limited by the field of the apparatus, which was fixed and not rotatable. A photograph shows two other cinematograph cameras fixed on the aeroplane.

Three flare lights were arranged on the wing. The distance between parallel wires in the field of one of the aeroplane cameras measured the movements of the elevator and was calibrated for this purpose.

Stop watches were placed in the field of both cameras and the beginning of the flare was co-ordinated within 1/30th second, with the aeroplane altitude and position. A detailed account is given of the method of controlling and reducing the observations.

Flights were observed with four different positions of the c.g. The results are given in graphical form and in tables and show the aeroplane position and

altitude and the elevator control angle as functions of time. A more extensive analysis of the test results is to be published later.

Eight references.

Blacking of Photographic Films by Electrons and by Induced Fluorescence. (B. v. Borries and M. Knoll, Phys. Zeit., Vol. 35, No. 7, 1/4/34, pp. 279-289.) (14.60/29453 Germany.)

Recent investigations of quantitative relations between the density of emitted electrons (coulombs/cm.) and the blackening of films for comparatively long time intervals (10^{-2} sec.) are extended to short intervals (10^{-5} sec. to 10^{-8} sec.).

Numerical tables and graphical charts give a mass of data for photographic plates and papers.

Twenty-one references.

Acoustics, Noise Reduction, etc.

Perception of Change in Intensity of Pure Tones. (B. G. Churcher, A. J. King and H. Davies, Phil. Mag., Vol. 18, No. 122, Supplmt., Nov., 1934, pp. 927-939.) (15.20/29454 Great Britain.)

A description is given of the methods of changing intensity and of precautions taken in presenting these changes to selected observers for personal judgment.

The numerical results are tabulated and shown graphically for a frequency of 800 cycles per second and indicate that Fechner's law of logarithmic increment of sensation is a rough approximation.

Five references.

Minimum Perceptible Changes of Intensity. (H. Davies, Phil. Mag., Vol. 18, No. 122, Supplmt., Nov., 1934, pp. 940-949.) (15.26/29455 Great Britain.)

The methods of the previous paper are used. More or less established results of other workers are shown graphically for a range of pitches from 50 cycles per second to 800 cycles per second.

Further data are shown graphically. Both the method of minimum change of intensity and of direct comparison were used and lead to closely similar curves.

The inadequacy of Fechner's law is confirmed.

Eight references.

The Measurement of Altitude and Inclination of Aircraft by Echo Method. (L. P. Delsasso, J. Acoustical Soc. of America, Vol. 6, No. 1, 1934, pp. 1-15; see Phys. Berichte, No. 22, 15/11/34, p. 1844.) (15.26/29456 U.S.A.)

Height and inclination of airship are estimated from time of reflection and flight speed and difference of frequency between emitted and reflected sounds.

Noise in Aeroplanes and its Suppression. (F. Gutsche, Z.V.D.I., Vol. 78, No. 27, 7/7/34, pp. 825-827.) (15.38/29457 Germany.)

The principal sources of noise in aeroplanes are the engine, the exhaust and the airscrew. The exhaust noise can be reduced to the level of engine noise by suitable silencers.

Air-cooled engines emit more noise than water-cooled engines and sleeve valves emit appreciably less noise than poppet valves. Airscrew noise measured in decibels increases linearly with tip speed, the noise also increases with blade thickness and pitch. The difficulties of silencing are increased by the width of the acoustical spectrum.

It is an immediate consequence of the approximate logarithmic scale of noise that the most intense source of sound must be reduced before less intense sources can be usefully attacked.

Sound insulation of passenger cabins is only a palliative and involves serious additions to weight.

Fourteen references.

Measurement of Absorption and Reflection of Sound by Materials. (F. Spandock, Ann. d. Phys., Vol. 20, No. 3, June, 1934, pp. 328-344.) (15.38/29458 Germany.)

A short sharp sound is emitted from a loud speaker and sets up a short wave train, part of which meets a microphone; the remainder passes on to a plate or board of the material under examination, placed at right angles to the line joining loud speaker and microphone. The wave train must be shorter than twice the distance between microphone and board, in order to avoid interference. Oscillograms are recorded and the different amplitudes measured.

The proportion of sound energy reflected is readily calculated from knowledge of the distances between loud speaker, microphone and board. Examples of oscillograms are reproduced.

The experiment may also be arranged to measure oblique reflection and to measure direct transmission through the specimen.

Eleven references.

Acoustics of Small Concert Halls. (G. V. Békésy, Ann. d. Phys., Vol. 19, No. 6, April, 1934, pp. 665-679.) (15.38/29459 Germany.)

A diagrammatic sketch shows the circuit of the installation used for establishing slowly increasing and decreasing notes. Oscillograph records are reproduced, which show examples of growth and decay.

A diagram reproduced the record of pressure distributed after three time intervals, for two different durations of the initial note and for ten points in a room of 180 m.^{3}. The frequency of occurrence of notes and of intervals is shown for the first violin in Beethoven's fifth symphony.

Proceeding to the determination of the acoustics of the room, the reverberation time was altered by changing the damping value of the hangings until the most pleasing effect was obtained by ear. The corresponding reverberation times for different tone pitches was measured at the same time. The distribution of reverberation times is shown graphically for the most pleasing effect and for other damping values.

Ten references.

A Method of Comparing Acoustical Impedances. (K. Schuster, Phys. Zeit., Vol. 35, No. 10, 15/5/34, pp. 408-409.) (15.38/29460 Germany.)

A telephone produces a pure tone in the straight main tube. Two auxiliary tubes have a junction at their mid-points. One of them, having fixed reactance, forms a loop between two points equidistant from the mid-point of the main tube; the other has variable reactance controlled by a double piston fitting into the two open ends. The pistons in turn have adjustable reflecting intensities.

Applications can be made to determination of absorption and reflection of various materials.

Acoustic Measurements on Models. (F. Spandöck, Ann. d. Phys., Vol. 20, No. 4, July, 1934, pp. 345-360.) (15.38/29461 Germany.)

The wave length must be reduced on the same scale as the dimensions of the model. Hence for one-fifth scale model the pitch of the corresponding note must be increased by two octaves and a major third.

A gramophone record and loud speaker run at five times normal speed supplies the source. The sound arriving at a fixed point is recorded on a record also run at five times normal speed. The latter record, run at normal speed, gives the full-scale effect, including any disturbance effects.

Precautions must be taken in selecting and damping the wall material. A number of records are reproduced and it is stated that the results are in agreement with full-scale measurements.

Twenty references.

Methods of Astronomical Air Navigation. (A. Bastide, Rev. de l'Armée de l'Air, No. 59, June, 1934, pp. 653-672.) (15.5/29462 France.)

Italian experts are paying attention to problems of night flying. If a schedule of corresponding times and positions can be prepared beforehand, close check on the accuracy of navigation is obtained by single star observations.

Accidents and Precautions

Contribution to Parachute Research. (R. Alkan, L'Aéron., No. 179 (Bulletin), April, 1934, pp. 37-43.) (16.20/29463 France.)

The porosity of the parachute material is measured by comparing the air flow through the material with that of a standard calibrated orifice. It appears that increase in air pressure increases the porosity by separating the fibres. Resistance to tearing is tested by an impact of a falling weight on a stretched strip of material (much as in tests on a length of chain). The maximum pull during the descent of the parachute is recorded by inserting a steel ball resting on a copper plate between the parachute and the load. This indication is rough because the time of contact is short. The temperature effect may be marked.

A simple type of magazine camera is described, which records the descent of full-scale parachutes.

Analysis of Parachute Emergency Descents and Accidents in Germany during 1933. (H. von Stryk, Flugsport, Vol. 26, No. 13, 27/6/34, pp. 278-279.) (16.20/29464 Germany.)

Three pilots saved their lives by emergency parachute descents, two from aeroplanes in a spin and one from a glider which broke up in the air.

There were four accidents, one fatal, in pre-arranged descents; two were caused by bad weather, one by faulty construction of parachute and one by careless operation.

Measurement of Lightning Currents. (Z.V.D.I., Vol. 78, No. 28, 14/7/34, pp. 862-863.) (16.30/29465 Germany.)

A bundle of highly remanent steel wire sealed in a glass tube is placed in close proximity to the lightning discharge and the intensity and direction of the current is estimated from the intensity and polarity of the remanent magnetic field induced in the wire.

More than 10,000 of these elements were placed on electrical pylons in 1933. The lightning is usually a negative discharge from cloud to earth with a duration of the order of 100×10^{-6} seconds and peak values of 60,000 amps.

Two references.

Aviation Rescue Boats. (Sci. Am., Vol. 151, No. 1, July, 1934, p. 38.) (20.34/29466 U.S.A.)

An illustration shows a high speed motor boat for salvage work in connection with naval aircraft forced down at sea; overall length 45 feet, two converted aircraft engines of 650 h.p. each, speed 45 m.p.h. The crew of six includes doctor, hospital attendant and aviation carpenter's mate.

Aircraft—Unorthodox

The Problem of Vertical Flight. (J. H. Crowe, Airc. Eng., Vol. 6, No. 69, Nov., 1934, and No. 70, Dec., 1934, pp. 315-318.) (17.05/29467 Great Britain.)

The principles of the autogiro and cyclogiro are discussed in terms of aerodynamical elements.

Photographs show an autogiro in flight and two types of cyclogiro on the ground. The helicopter is considered to be fundamentally unstable in gusts.

Variable Incidence Gyroplane. (Flight, Vol. 26, No. 1357, 27/12/34, pp. 1377-1378.) (17.05/29468 Great Britain.)

In the Kay gyroplane the rotating wings do not flap but operate at a fixed incidence which, however, is controllable by hand. The hub can be tilted to maintain trim.

It is claimed that by reducing the incidence at high speed, the cone angle and drag of the rotating wing can be reduced. An increase in incidence reduces landing impact; a negative incidence on the ground steadies the aircraft in a gusty wind.

Flying trials are awaited.

Rotating Wings. (M. Schrenk, Luftwissen, Vol. 1, No. 5, 15/5/34, pp. 121-127.) (17.05/29469 Germany.)

A descriptive technical account is given of the relation between the aeroplane wing and the autogiro and helicopter blade. The elementary aerodynamical conditions for autorotation are shown in a diagram of forces on a wing element.

An interesting variant of the autogiro is the so-called " gyroplane " in which variable incidence is obtained by rotating mechanically pairs of blades about a common axis (which is a diameter of the blade disc). Clearly increase of incidence of one blade is accompanied by equal decrease of incidence of the opposite blade.

The Florinne and Asboth machines are helicopters, in the usual sense of the name, with blades rigidly attached to the shaft. An English report on the latter is cited, in which it is stated that the machine is stable in calm air, with a sensible vertical climb (1.5 m./s.) and light landing.

Photographs show a Cierva autogiro, a Rieseler gyroplane and a Florinne helicopter in flight.

Ten references.

The Technical Value of the Rotating Wing Aircraft. (M. Schrenk, Z.V.D.I., Vol. 78, No. 25, 23/6/34, pp. 776-777.) (17.05/29470 Germany.)

The low landing speed of the autogiro facilitates taking up and dropping messages and even personnel. It should replace the vulnerable captive balloon for artillery and is more likely to survive a forced landing in fog than an aeroplane.

Seven references.

Choice of Aerofoils for Rotating-Wing Aircraft. (J. B. Wheatley, J. Aer. Sci., Vol. 1, No. 2, April, 1934, pp. 88-90.) (17.05/29471 U.S.A.)

A brief account is given of the aerodynamic basis of the autogiro and a semi-empirical expression is quoted from R. & M. 1127. The rule is given that the drag coefficient be small up to three-fourths of maximum lift.

The outstanding difficulties of the physical theory are considered intractable.

The Autogiro Fitted with Publicity Streamers. (L'Aéronautique, No. 181, June, 1934, pp. 135-136.) (17.05/29472 France.)

Extensive use is made of the autogiro in U.S.A. for trailing publicity banners. The messages are made of individual letters (up to 35) about seven feet high

strung on a wire frame and kept taut by two air cones at the ends. The conditions for stability of the streamer have been found empirically.

Rocket Flight. (G. E. Pendray, Sci. Am., Vol. 151, No. 1, July, 1934, pp. 10-12.) (17.20/29473 U.S.A.)

A useful account is given of the relative weights of fuel consumption and pay load for a rocket design. The so-called speed of escape from the earth's attraction is 7 m.p.s. and about 25 m.p.s. from the sun's attraction.

The trial design of a rocket shows that to attain the former speed the total weight (mostly combustible) is about 500 times the pay load. Modest experimental results are described and a photograph shows a rocket at the moment of departure.

Reference is made to German, U.S.A. and British Rocket Societies, each with its own publications.

Aircraft Carriers

Seaplane Carriers. (Sci. Am., Vol. 151, No. 1, July, 1934, p. 42.) (18.01/29474 U.S.A.)

A photograph shows U.S. " Saratoga " with about twenty large and fifty small aircraft on the flying deck.

Seaplane Tender-Ship " Westfalen." (F. W. Hammer, Z.V.D.I., Vol. 78, No. 22, 2/6/34, pp. 649-656.) (18.04/29475 Germany.)

A detailed descriptive account is given of the seaplane and flying boat hoisting and catapulting equipment. The trailing canvas is shown in operation.

Four references.

Meteorology and Physiology

Determination of Dust Content in the Free Atmosphere. (R. Meldau, Z.V.D.I., Vol. 78, No. 20, 19/5/34, pp. 614-615.) (19.10/29476 Germany.)

Respiration troubles are caused by quartz dust and a determination of quartz content of atmospheric dust is effected as follows.

A filter passes particles below a certain size, which are deposited on a glass plate for examination under a microscope. A count is made of the particles visible under the microscope. The plate is then moistened with tetralin, the quartz particles disappearing, since the refractive index of quartz is near that of tetralin, and a second count is made of the particles remaining visible.

Atmospheric Dust Recorder. (W. G. Hazard, J. Frank. Inst., Vol. 217, No. 5, May, 1934, pp. 571-590.) (19.10/29477 U.S.A.)

Dust collected from the atmosphere is deposited on a film in a beam. The diminution of a beam of light passing through the film and deposited dust is recorded by photocell, and the current is amplified in the usual way. The light reduction may be proportional to area multiplied by number, *i.e.*, $N \cdot V^{2/3}$ when N is the number, V the mean volume of the particles. In any case it is not a measure of number or size independently.

Fourteen references.

Determination of the Variation of Suspended Soot in the Atmosphere. (A. Heller, Z.V.D.I., Vol. 78, No. 18, 5/5/34, pp. 565-567.) (19.10/29478 Germany.)

The experiments were carried out in Berlin and neighbourhood using an Owen filter apparatus. The variation of soot content with the hour of the day and the season is similar to that observed in English tests, but the absolute

quantities are considerably less. Wind and rain and vertical temperature gradient have pronounced effect.

The marked increase in soot content after sunset is due to the evening temperature inversion preventing the influx of fresh air into the contaminated ground layer.

(Possibly gas attacks will be more effective two hours after sunset.)

Three references.

Prevention of Ice Formation on Wings in the U.S.A. (L'Aéronautique, No. 181, June, 1934, p. 138.) (19.15/29479 France.)

A hollow rubber band is periodically inflated and deflated and causes the ice to crack off. Failure to act under severe conditions caused the wreck of an air liner and the frequency has been increased from 40 to 80 per minute to meet this danger. The device is apparently standard on all postal aeroplanes.

Reference is made to fitting a rubber sheet over the airscrew hub and half way along the blades. The surface is treated with castor oil before every flight and prevents ice formation on the airscrew.

Physical Aptitude Tests for Pilots. (Dr. Flamme, Revue de l'Armée de l'Air, No. 60, July, 1934, pp. 761-786.) (19.29/29480 France.)

The expansion of the French Air Force will mitigate the present severe regulations governing the acceptance of pilots and the high proportion of rejections. The medical officer should be in sympathetic relations with the pilots and frequent rest periods should be granted to prevent staleness.

Lighting

Drag of Landing Lamp. (C. H. Dearborn, N.A.C.A. Tech. Note No. 497, May, 1934.) (21.07/29481 U.S.A.)

Dimensioned sketches and photographs show details of landing lamps mounted in the leading edge and below the wing, with and without fairing.

Full-scale drag measurements are given graphically for six arrangements. Faired lamps in the leading edge show the lowest drag curve, with a minimum at $-5°$ incidence.

Six references.

Advances in the Technique of Illumination. (H. Lux, Z.V.D.I., Vol. 78, No. 15, 14/4/34, pp. 451-454.) (21.07/29482 Germany.)

Modern illuminators are of the high temperature type (solid radiator) or low temperature type (gas radiator). In the former the problem is to increase the temperature of the filament and the effective illumination while maintaining reasonable life. In the second type the problem is to control the colour without undue loss of illumination. Outputs of the order of 36 lumens per watt have been obtained with high temperature filament lamps for films. Experiments are being conducted with filaments of tantalum carbide, with a melting point about 500°C. higher than that of tungsten (about 3,000°C.).

With low temperature vapour lamps the type of radiation emitted is controlled by fitting fluorescent containers. Vapour pressure influences the spectral lines and a mixture of vapours of the rare earths give an approach to white light.

A new photometric apparatus is described, which takes account of differences in wave length or colour.

Twenty-four references.

High Class Products of the German Electro-Ceramic Industry. (J. Wallich, Z.V.D.I., Vol. 78, No. 17, 28/4/34, pp. 522-524.) (21.08/29483 Germany.)

Successful results have been obtained both in construction of large scale ceramic insulation with mechanical strength as a predominant requirement and in insulating materials for special purposes.

An insulator with a magnesium base has a dielectric loss factor approaching that of quartz and is specially suited for short wave wireless sets. A material with a dielectric constant of about 100 has been produced with which a disc condenser of 1 cm. diameter and 20 cm. capacity has been constructed.

Seven references.

Use of Phosphorescent Substance for Aeronautical Purposes. (M. Roulleau, Pub. Sc. et Tech., No. 48, 1934.) (21.12/29484 France.)

A list is given of common phosphorescent substances and a simple photometer is described for measuring feeble illumination.

Aerodynamics and Hydrodynamics

Diffusion of Heat and Vorticity with (Initial) Circular Cylindrical Symmetry (of Distribution). (W. Muller, Ann. d. Phys., Vol. 19, No. 8, May, 1934, pp. 809-828.) (22.0/29485 Germany.)

The present paper is restricted to problems analogous to the diffusion of heat by thermal conductivity. Following Kelvin (Collected Papers, Vol. II, pp. 41-60), a number of Fourier's integrals are constructed and evaluated, involving Bessel functions.

The results are shown graphically for initial distribution along a line over a circular cylindrical surface and through a circular cylindrical volume.

Nine references.

Contribution to the Study of Lubrication. (M. Briault, Pub. Sc. et Tech., No. 46, 1934.) (22.0/29486 France.)

The author has measured by torsion balance the coefficient of sliding friction at very low speeds with a number of oils. With vegetable oils increase in temperature has small effect up to a certain critical value, beyond which there is a sudden drop in the friction. The drop is roughly the same for all the oils examined, but the critical temperature varies considerably for different oils.

It appears that the change is due to the action of certain organic acids normally present in the oil and addition of such substances to mineral oils reduces the coefficient of sliding friction.

Flow Through Blade Grids. (F. Weinig, Z.V.D.I., Vol. 78, No. 24, 16/6/34, pp. 742-746.) (22.0/29487 Germany.)

In the old turbine theory the space between consecutive blades is considered as a channel through which the fluid is guided. The modern tendency is to increase the spacing, in which case each blade tends to become an aerofoil, the foil now becoming affected by interference.

The author develops simple expressions for the hydrodynamical reaction on the blades.

Seventeen references.

Wind Structure on Evaporation in a Turbulent Atmosphere. (O. G. Sutton, Proc. Roy. Soc., Vol. 146, No. 858, 1/10/34, pp. 701-722.) (22.0/29488 Great Britain.)

The equations of motion are first considered and a summary is given of the methods of Taylor, Prandtl, v. Kármán and others.

Empirical expressions are formed for various statistical mean values with appropriate physical dimensions, integrated and differentiated.

In view of the complete failure of mathematical physical analysis it is difficult to consider the results otherwise than as empirical formulæ of the correct dimensions.

Similar methods are applied to the problem of evaporation and integral expressions are formed. Fits are obtained between a variety of empirical forms on observed values.

Twenty-seven references.

Kinetic Theory of Viscosity of Liquids. (R. O. Herzog and H. Kudar, Phys. Zeit., Vol. 35, No. 11, 1/6/34, pp. 437-445.) (22.10/29489 Germany.)

The methods of molecular theory are applied and expressions are formed for the coefficient of models represented by a sphere, an ellipsoid of rotation (axes 1, 1, 2), an elongated cylinder and a tetrahedron.

The results are applied to fluids with molecules of different type.

Six references.

Effect of Electrostatic Field on Viscosity. (R. O. Herzog, H. Kudar and E. Paersch, Phys. Zeit., Vol. 35, No. 11, 1/6/34, p. 446.) (22.10/29490 Germany.)

An electrical field of 100 volts orients asymmetrical molecules so as to increase the time of flow in a viscosimeter and the results are given in a table.

Times are unaltered for molecules with approximately spherical symmetry and are increased where there is pronounced asymmetry.

Flow of Perfect Fluid Through a Lattice of Aerofoils. (E. Weinel, Ing. Arch., Vol. 5, No. 2, April, 1934, pp. 91-105.) (22.10/29491 Germany.)

The problem is two-dimensional throughout. Expressions can be written down for conformal representation, on a circle, of a lattice of flat thin blades regarded as segments of a straight line, and give the potential function of the velocity field.

The extension to blades of the form of a circular arc has been worked out numerically by other authors, and involves three numerical coefficients, the values of which are given graphically as functions of gap and angle of stagger of the lattice.

An approximate extension is made to blades of other forms, with restrictions to thin aerofoils of small curvature. One blade only is given aerofoil shape, the others are replaced by thin flat blades. The blade is transformed into a slightly distorted circle, called here an "ovaloid." Taking distance along the blade as variable, the velocity is expressed by an integral equation, the integral being taken over the ovaloid. The integral equation can be solved by successive numerical approximations.

Extensive numerical comparisons between the values given by the solution for flat blades and measurements with blades of usual shapes are shown in 24 diagrams of lift as a function of incidence and 27 diagrams of pressure distributions. Three diagrams show lift as a function of gap in a Kaplan turbine. The agreements are close, apart from a moderate scattering in some of the examples.

Thirteen references.

Motion of an Eddy Near Rectilinear Boundaries. (E. Paul, Z.A.M.M., Vol. 14, No. 2, April, 1934, pp. 105-116.) (22.10/29492 Germany.)

The methods of complex algebra are applied and examples are worked out for semi-infinite and finite plane boundaries and for a finite gap in an infinite plane.

The calculated paths are shown graphically for different initial paths in relation to different types of boundary.

Nine references.

A Numerical Method of Conformal Representation to a Doubly Connected Region. (K. Zarankiewicz, Z.A.M.M., Vol. 14, No. 2, April, 1934, pp. 97-104.) (22.10/29493 Germany.)

The problem of transforming a rectangular transformer stamping with two rectangular windows into a region by concentric circles is considered.

The solution of an integral equation is required and is obtained by expansion in power series to the fourth positive and negative powers of the complex variable.

Numerical coefficients are worked out for the expansion, but no application is made to a complete numerical example. The method has application to irrotational flow of a fluid.

Eight references.

Disturbance of Steady Inviscid Flow Between Parallel Planes. (J. L. Synge, Phil. Trans. Roy. Soc., Vol. 234, No. 732, 31/12/34, pp. 43-78.) (22.15/29494 Great Britain.)

The problem is restricted to two-dimensional cases and has therefore restricted relation to physical phenomena. The author examines the so-called velocity-characteristic value method, applied by Kelvin and Rayleigh to the problem of instability and shows that it is not valid for the present problem. In particular, he challenges Rayleigh's result that the flow is stable if the velocity profile has curvature of the same sign throughout.

The vorticity is introduced as a parameter and the vector of velocity (expressed as a double integral of vorticity through the fluid) is used to define the resultant velocity of the fluid at any part.

The integro-differential equation is expanded in series which involve new functions. The expressions are generalisations of those used by Rosenhead for a single sheet of vorticity replaced by a discrete row of point vortices.

Special forms are obtained for an initial parabolic velocity distribution between the plane boundaries.

The author hopes that the results contain the correct solution of the problem.

Eighteen references.

Turbulence. (H. L. Dryden, J. Aer. Sci., Vol. 1, No. 2, April, 1934, pp. 67-75.) (22.15/29495 U.S.A.)

The questions are raised of defining turbulence and of measuring the quantity so defined. Wind channel experiences are referred to and compared with full-scale experience of the atmosphere.

The effects of turbulence on the resistance of spheres and aerofoils are referred to. The relations between turbulence and the Reynolds number are mentioned. Unsolved problems are stated.

Twenty references.

Divergent Flow of Fluid. (W. R. Dean, Phil. Mag., Vol. 18, No. 121, Nov., 1934, pp. 759-777.) (22.2/29496 Great Britain.)

Hamel found a solution of the problem of radial flow of a viscous fluid for steady conditions and demonstrated the existence of particular steady motion differing slightly from radial flow.

A more general investigation is given in the present paper and in the course of numerical computations solutions are obtained, some of which are identified with Hamel's, others appear to be new.

A discussion is given of the difficult problem of stability in the presence of small disturbances imposed at entry. The periods are given by the vanishing of an infinite determinant, of which the first diagonal minor of the fourth order is taken as an approximation and the zeros shown numerically and graphically for four assumed values of the greatest root in the cubic of the Weirstrass elliptic integral.

It is stated as a qualitative result that certain types of disturbance produce instability in radial flow.

Five references.

Flow in Curved Pipes. (H. Nippert, Forschungsarbeiten, No. 320, 1929.) (22.2/29497 Germany.)

In an historical note curves of loss and configuration of flow are reproduced graphically from previous papers by other experimenters.

A detailed description of the author's elaborate installation is illustrated with photographs and diagrams. The pitot-mean velocity distribution is measured at the outlet of the channel, where a free jet is discharged. Bends of 90° and 180° were set up in channels of various sections, one circular and six rectangular, with different side ratios. The cross sectional areas were between 5 cm.^{2} and 15 cm.^{2}, the radius of curvature of the order of twice the channel depth. The curve and cross section of minimum loss for this type of flow is sought experimentally.

Twenty-three photographs are reproduced and show lines of flow, in some cases laminar, in some with local eddy regions, and in some with more extensive turbulence. Over fifty diagrams of transverse flow are reproduced.

Fifty references.

Pressure Fall in Smooth Curved Pipes. (H. Richter, Forschungsarbeiten, No. 338, 1930.) (22.2/29498 Germany.)

Measurement of pressure drop was made in a smooth circular pipe of about 4 cm. diam. fitted successively with twenty-one bends of radii 3.4 cm. to 1 metre, subtending from 10° to 180°.

Two diagrammatic sketches show typical streamlines in side elevation and projected on a transverse cross section. Extensive numerical results are tabulated and shown graphically as functions of the Reynolds number. Smooth transition is shown from laminar to turbulent motion between $R=1660$ and $R=2400$ (Fig. 25).

Forty-five references.

Steady Laminar Flow of Viscous Fluid in a Rectangular Pipe. (J. Allen, Phil. Mag., Vol. 18, No. 119, Sept., 1934, pp. 488-495.) (22.2/29499 Great Britain.)

The equations of motion have been solved by Cornish and some numerical consequences are discussed.

The ratio of axial velocities is shown to be a maximum (2.10) for a square section and falls off to 1.5, the limiting ratio, for parabolic distribution between indefinitely wide planes as a limiting case.

Contours of mean velocity are plotted graphically for a square and for the aspect ratio $10/\pi$.

Two references.

Surface Friction of Ships. (W. Schmidt, W.R.H., Vol. 15, No. 9, 1/5/34, pp. 101-105.) (22.3/29500 Germany.)

The paper cites the rational expression of Blasius for laminar flow and the empirical expression of Nikuradse for turbulent flow, both giving a coefficient of

surface friction in terms of the Reynolds number. Numerical values are given graphically. These expressions are elaborated along the lines of the Göttingen Laboratory and numerical values are given graphically and in tables for wide ranges of the variables.

Numerical data for warships from the Vienna and Hamburg Laboratories are tabulated and compared.

Four references.

Wave Patterns and Wave Resistance. (T. H. Havelock, Engineering, Vol. 138, No. 3577, 3/8/34, pp. 125-126. Summer Meeting of Institution of Naval Architects.) (22.35/29501 Great Britain.)

A summary is given of the development of wave theory and applications are made to ship form. The solution involves the use of a function which has been determined only for limiting forms and appears to give results 15 to 20 per cent. low in approximate applications.

Consideration of the energy of the wave field at a distance gives a measure of the wave resistance.

Toepler's Refraction Method. (H. Schardin, Forschungsheft, No. 367, July/Aug., 1934.) (22.36/29502 Germany.)

A beam of light passing through air, with a variable field of density, is refracted differentially and projects on a screen a field of variable light density, which may be interpreted in terms of variable density qualitatively and in some cases quantitatively.

In particular, photographs of bullets in flight and of currents of air near heated wires show well-defined light and dark bands which may be interpreted as wave fronts or as fluid lines in the respective cases.

A useful exposition is given of the physical and geometrical optical relations involved, with a critical discussion of the accuracy of the methods of reduction and interpretation of the observations with methods of numerical application.

Many photographs are reproduced in illustration of the methods, including the indication of fluid lines in wind channels. The isoclinic lines round a heated tube yield two remarkable photographs and their interpretation in terms of the temperature field is worked out numerically.

Seventy-six references.

" Diruttore " Turbulence Wing. (Flugsport, Vol. 26, No. 13, 27/6/34, pp. 31-32.) (22.45/29503 Germany.)

At stalling incidence the flow of air is diverted from the upper wing surface near the leading edge while still in a laminar state. The branching off can be delayed if turbulence is introduced into the layer.

In the Italian construction described the " spoiler " consists of an aluminium tube of oval section (10 x 20 mm.) placed about 20 mm. in front of the nose of the wing. The exact orientation of the tube is important and this has to be determined experimentally. The weight of the contrivance is less than 3lb. per wing for a Caproni light aeroplane. The maximum speed is slightly reduced (3 km. per hr.). On the other hand, the machine so fitted will glide at 60 km. per hr. at 17° with full aileron control.

(The above does not appear to be quite concordant with Prandtl's explanation that stalling is postponed by removing the accumulation of retarded fluid in the boundary layer.)

Experimental and Mathematical Researches on Flow Stability. (W. Margoulis, Tech. Aeron., No. 132, 1934, pp. 65-148.) (22.45/29504 France.)

The researches covered date from those of Fliegner (1898) to recent work of Nikuradse (1929). A review is given mainly of work on stability of flow in

expanding channels (diffusers). In the experiments the air stream pressure, slightly above atmospheric, evacuates the boundary layer through slots in the diffusor wall and nearly uniform velocity distribution is obtained even in short diffusors. The air loss was about 2 per cent. of the flow. Steadiness of flow was indicated by silk threads.

Six references.

Propulsion by Reaction. (I. Raffaelli, Riv. Aeron., Vol. 10, No. 6, June, 1934, pp. 463-472.) (22.5/29505 Italy.)

An elementary discussion is given of the propulsive efficiency of " closed " and " open " circuits. In the former the gas is at rest relatively to the explosion chamber before combustion, in the latter it is in relative motion.

Investigation of the Transition Layer at the Surface of a Wing in Flight. (J. Stuper, L.F.F., Vol. 11, No. 1, 15/5/34, pp. 26-32.) (22.6/29606 Germany.)

A sketch shows the mounting of a pitot head with position adjustable along the chord and above the wing surface. Extensive explorations are plotted graphically for four different flying speeds and for eleven stations along the chord on the suction side and eight on the pressure side. Static pressure readings were obtained from orifices in the surface of the wing.

The point of change from laminar flow to turbulent flow is well marked by the change in the velocity profile from one station to another, both in the velocity profiles and in the pressure distribution. The results are concordant with model tests.

Twelve references.

Effect of the Surface Condition of a Wing on the Aerodynamic Characteristics of an Aeroplane. (S. J. de France, N.A.C.A. Tech. Note No. 495, April, 1934.) (22.6/29507 U.S.A.)

Experiments carried on in the full-scale channel show that polishing the wing surface has a negligible effect on the lift, but reduces the drag. The effect is not great and at 200 m.p.h. would produce a speed increase of say, 1.5 per cent., corresponding to about $4\frac{1}{2}$ per cent. in power.

Materials—Elasticity and Plasticity

Electrically-Maintained Vibrating Reed and Determination of Young's Modulus. (R. M. Davies and E. G. James, Phil. Mag., Vol. 18, No. 122, Nov. (Supplmt.), pp. 1023-1052, and No. 123, Dec., 1934, pp. 1053-1086.) (23.10/29508 Great Britain.)

Small reeds of phosphor bronze with strips of " Stalloy " transformer iron attached at the tips were maintained in vibration by an alternating magnetic field. The mathematical theory is worked out and the relations between resistance, impedance, frequency and amplitude of reed vibration are obtained. The value of Young's modulus was obtained from three reeds and showed a variation of about 1 in 1,000.

The value of Young's modulus deduced is nearly 12×10^{11} dynes/cm.^{2}, in closer agreement with Kay and Laby than could be expected from an alloy subject to variation in composition and treatment.

Method for Determination of Torsional Stresses by Means of a Diaphragm Model. (E. Kopf and E. Weber, Z.V.D.I., Vol. 78, No. 30, 28/7/34, pp. 913-914.) (23.10/29509 Germany.)

In applying the well-known analogy of Prandtl the author prepares a mould of the strained diaphragm in a suitable plastic material and makes the measurements from the mould.

Three references.

Plastic Materials. (H. Bürgel, Z.V.D.I., Vol. 78, No. 17, 28/4/34, pp. 519-522.) (23.10/29510 Germany.)

Plastic materials cover a very wide range. Artificial resins with a phenolic base such as Bakelite are well known. Products with cellulose and albumen as bases are now being developed. The polymerisation and condensation of certain carbohydrates furnish new bases.

Four references.

Plastic Behaviour in the Light of Creep Elastic Recovery Phenomena. (M. F. Sayre, Trans. A.S.M.E., Vol. 56, No. 7, July, 1934, pp. 559-561.) (23.10/29511 U.S.A.)

The amount of creep and hysteresis seem to be definitely related to the temperature of the metal and to its state of internal stress. Very mild heat treatment may greatly decrease hysteresis, whilst overloads beyond the elastic limit greatly increase it.

The author put forward several hypotheses in tentative explanation.

Elastic Bending of Curved Bar. (E. Jones and R. J. Cornish, Phil. Mag., Vol. 18, No. 119, Sept., 1934, pp. 456-458.) (23.10/29512 Great Britain.)

The strain energy is usually calculated without taking into account the change in the depth of the bar. An additive term is given as a (formally simple) integral.

A Membrane Analogy Supplementing Photo-Elasticity. (J. G. McGivern and H. L. Supper, J. Frank. Inst., Vol. 217, No. 4, April, 1934, pp. 491-504.) (23.15/29513 U.S.A.)

From Authors' Abstract.—A description is given of a method suggested by J. P. Den Hartog for finding the sum of the principal stresses in a two-dimensioned model by ordinate measurements on a stretched rubber membrane.

The method is applied to a bar with a central circular hole in tension. It is easy in operation and sufficiently accurate.

Field of Stress in Rectangular Plates. (F. Tölke, Ing. Arch., Vol. 5, No. 3, June, 1934, pp. 187-237.) (23.30/29514 Germany.)

The elastic equations are formed in rectangular and polar co-ordinates. General solutions in rectangular co-ordinates are given in the form of series integral equations, involving trigonometrical and hyperbolic functions.

In polar co-ordinates Bessel functions are not introduced explicitly, but solutions in series are formed and numerical coefficients are computed. The membrane analogy is introduced and the assumption of rectangular nodal lines leads to solutions in Jacobi elliptic functions, numerical results being computed for an aspect ratio of 2/1. Theta functions are also applied and a numerical case worked out for the aspect ratio 4/3.

There are 240 numbered equations in the paper.

Eight references.

Strength of Tubular Struts. (J. Morris, Airc. Eng., Vol. 6, No. 69, Nov., 1934, pp. 303-304.) (23.30/29515 Great Britain.)

The approximate (Southwell) formula for buckling load gives values slightly in excess for very thick struts and in defect for thin struts.

A family of modified curves is computed to cover the whole range of diameter/gauge ratios more accurately.

Distribution of Moment in Continuous Beams. (H. A. Williams, Trans. A.S.M.E., Vol. 56, No. 5, May, 1934, pp. 305-319.) (23.30/29516 U.S.A.)

A method, due to Prof. Hardy Cross, is given for finding the moments at joints of a continuous beam without end thrust. Step by step approximations are made from joint to joint by simple arithmetic. Numerical examples are worked out in detail.

(Similar elementary methods may possibly be applicable to the more general case where there are end thrusts.)

Five references.

Design of Compression Members in Aircraft. (W. R. Osgood, Bur. Stan. J. Res., Vol. 13, No. 1, July, 1934, pp. 157-160.) (23.40/29517 U.S.A.)

A particular case of Berry's analysis is applied successfully to joints of a framework giving a sufficient number of linear homogeneous equations. The elimination of the unknown quantities gives a determinantal equation which is the condition for buckling.

Two references.

Vibration of Engine Mountings. (B. v. Schlippe, L.F.F., Vol. 11, No. 2, 3/7/34, pp. 57-63.) (23.40/29518 Germany.)

The elastic coefficients of a symmetrical lattice structure are investigated with applications to engine frame mountings.

One reference.

The Torsional Stiffness of Thin Duralumin Shells subjected to Large Torques. (P. Kuhn, N.A.C.A. Tech. Note No. 500, July, 1934.) (23.41/29519 U.S.A.)

A simple method is given of estimating the torsional stiffness of box beams or stressed skin wings. By means of charts the torsional deflections of eight beams and a complete wing are calculated in satisfactory agreement with experimental results.

Six references.

Rubber Spring Mounting for Machinery. (D. Thum and K. Oeser, Z.V.D.I., Vol. 78, No. 19, 12/5/34, pp. 587-589.) (23.46/29520 Germany.)

Experiments furnished the elastic and damping coefficients of rubber for the calculation of rubber cylinders, which are used successfully to damp the transmission of vibration and noise from machines through their foundations. The life of a cylinder depends on the quality of the rubber and the temperature rise.

Four references.

A Method Utilising Coupling Between Two Oscillating Systems for the Determination of Mechanical Strength of Structures. (P. Rolland and P. Sorin, Pub. Sc. et Tech., No. 47, 1934.) (23.46/29521 France.)

The transfer of energy between two vibrating systems depends on the elastic properties of the connecting structure. An elastic " deterioration " of the structure affects the transfer characteristic.

The authors hope to apply the method to a complicated structure such as an aircraft fuselage.

Lateral Vibration of Ring-Shaped Frames. (F. H. Brown, J. Frank. Inst., Vol. 218, No. 1, July, 1934, pp. 41-48.) (23.46/29522 U.S.A.)

The frame is regarded as a circular segment of about 320° with encastré ends.

An expression is formed for the potential energy of strain and the kinetic energy of vibration, and an approximate result is obtained for the frequency of vibration, which is within 3 per cent. of the observed values.

Four references.

Motor Car Vibrations and Their Insulation from the Frame. (K. Oeser, Autom. Tech. Zeit., Vol. 37, No. 10, 25/5/34, pp. 277-279.) (23.46/29523 Germany.)

A popular exposition of the advantages accruing from the extensive use of rubber in mounting engine and back axle in the frame.

Miscellaneous

The German Silent Typewriter. (W. Kniehahn, Z.V.D.I., Vol. 78, No. 18, 5/5/34, pp. 547-555.) (29524 Germany.)

A complicated system of linkages, regulated by the inertia of a flywheel, imposes a reciprocating motion on the type. An analysis of the sound spectrum shows a marked reduction of sound intensity, especially in the higher frequency range. The average sound intensity at a distance of 1 m. is 38 phones.

Nine references.

A Free Cutting Spade. (G. Lehmann, Z.V.D.I., Vol. 78, No. 16, 21/4/34, pp. 504-5.) (29525 Germany.)

The section of the blade is arrow-shaped so that the main shovelling surface is narrower than the cutting surface. The effort of digging is considerably reduced, since the material to be handled does not cling to the shovelling surface.

The Activities of the Reichanstalt during 1933. (S. Erk, Z.V.D.I., Vol. 78, No. 26, 30/6/34, pp. 296-799.) (29526 Germany.)

The following are among the items mentioned:—

1. Influence of short sound waves on chemical processes.
2. Laws of similarity (hydrodynamics) investigated down to low air pressures, covering the range *Re* 10^{-5} to 10^{5}.
3. Fog penetration—Development of infra red spectrum apparatus, enabling investigation of narrow spectral lines by means of a vacuum thermo element.
4. Stroboscopic investigation of roller bearings and measurement of creep of cage.

Nine references.

Tests of Uniformity in Series Manufacture. (Fr. A. Willers, Z.A.M.M., Vol. 14, No. 2, April, 1934, pp. 77-84.) (29527 Germany.)

The so-called Lexis number is defined for one and two variables in terms of mean square deviation from a mean zero.

Formal expressions are developed for correlation of deviations in selected sets of specimens for different production series.

The method has applications to correlation of deviations in different series of target records in which there are two main sources of error.

Four references.

Pressure of Saturated Water Vapour from 0° to 374°C. (N. S. Osborne and C. H. Meyers, Bur. Stan. J. Res., Vol. 13, No. 1, July, 1934, pp. 1-20.) (29528 U.S.A.)

German, British and American experimental values are compared with various empirical formulæ. The formula giving the closest mean fit is used for the preparation of numerical tables.

Five references.

The Specific Heat of Water from 0° to 350°C. and from Saturation Pressure to 260 kg./cm. (≈ 26 Atmospheres). (W. Koch, F.G.I., Vol. 5, No. 3, May/June, 1934, pp. 138-145.) (29529 Germany.)

Nineteen measurements of specific heat were made and 43 determinations of temperature change under adiabatic flow. Three empirical equations are fitted to three different ranges of temperature.

Numerical values are tabulated and some comparisons are made with other results. Above 270° the international tables gave higher values.

Twelve references.

Numerical Calculations of Ships' Gyros. (E. Hahnkamm, Ing. Arch., Vol. 5, No. 3, June, 1934, pp. 169-178.) (29530 Germany.)

The equations of motion are given and a numerical example shows that a gyro installation, with a mass only 1 per cent. of that of the ship, reduces the rolling angle from 30° to 1°.

Seven references.

ABSTRACTS OF PATENT SPECIFICATIONS

(Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.)

Abstracts of Patent Specifications received by the Society are published in the Journal. It should be noted that these abstracts are specially compiled by Mr. W. O. Manning, F.R.Ae.S., for the Journal and are only of those actually received and subsequently bound in volume form for reference in the library. These volumes extend from the earliest aeronautical patents to date, and form a unique collection of the efforts which have been made to conquer the air.

The Council accept no responsibility whatever for the accuracy of the abstracts and in any case of doubt the full patent can be consulted when necessary in the library of the Society.

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Aeroplanes, Construction

423,060. *Improvements in or Connected with Aircraft Fuselages.* The Blackburn Aeroplane and Motor Co., Ltd., Seaplane Base, Brough, East Yorkshire, and Bumpus, F. A., Elloughton, Brough. Dated Nov. 30th, 1933. No. 33,601.

The problem which this invention is designed to meet is the provision of fuel tanks which are readily removable without the limitation of being removable only through the cockpits, etc. The fuselage is of the monocoque type having an unobstructed aperture in its skin, preferably underneath, through which the tank may be introduced into or removed from the fuselage. This aperture is normally closed by a cover which is connected to or which forms part of the tank and which completes the continuity of the skin of the fuselage. The tank may be attached to the fuselage by bolts through the cover and steadying rings or devices may be used.

426,438. *Improvements in Windscreens for Aircraft.* Boulton and Paul, Ltd., Riverside Works, Norwich, and North, J. D., Hill House, Eaton, Norwich, and Bannell, 16, Newmarket Road, Norwich. Dated Feb. 6th, 1934. No. 3,849.

The windscreen described consists of three portions: a front portion fixed in position on the aircraft, a middle portion which normally mates with the front portion, but which is arranged on rails on the aircraft body, so that it may slide back, and a rear streamlined body which is also attached permanently to the aircraft. When the middle portion is pushed forward so as to mate with the front portion the whole forms an enclosed cabin, and as all portions are covered with a transparent substance the pilot's view is excellent. Should, however, the pilot prefer an open cockpit, he can push back the middle portion. The front portion then acts as an ordinary windscreen and the view is similar to that from an open cockpit.

426,268. *Improvements in and relating to Wings for Aircraft.* Vickers (Aviation), Ltd., and Wallis, B. N., both of Weybridge Works, Byfleet Road, Weybridge, Surrey. Dated Sept. 28th, 1933. No. 463/35 (divided out of 426,134).

It is stated that in the case of single spar wings for aircraft there is considerable difficulty in providing in the wing accommodation for a retracted chassis, petrol tank, etc., owing to the position of the wing spar. It is proposed to obviate this difficulty by splaying the upper and lower booms of the spar in the neighbourhood of the fuselage, so that the retracted chassis or the petrol tank may be accommodated between them.

Aeroplanes—General

422,980. *Improvements in or Relating to Aeroplanes.* Ruolle, M. A., 19, Rue Richard Lenoir, Paris, France. Convention date (France), Dec. 30th, 1932.

This arrangement consists of a propellerless aeroplane wherein a vacuum is produced above the machine and a pressure below. The engine drives exhausters which produce a reduction of pressure in the interior of the wings which are provided with a slot opening to the atmosphere and situated near the leading edge. The air is discharged underneath the aeroplane and there is a deflector for increasing the propulsion by deflecting the air rearwards.

427,186. *Improvements in or relating to Tailless Aeroplanes.* Petters, Ltd., and Capt. G. T. R. Hill, both of Westland Aircraft Works, Yeovil, Somerset. Dated Oct. 17th, 1933. No. 28,709.

This specification refers to tailless aircraft of the pterodactyl type, and refers specifically to machines in which the swept back portion of the wings constitute the main supporting surfaces, and in which the centre section is substantially straight and does not exceed 40 per cent. of the total span of the wings. The wing tip control surfaces are located wholly behind the trailing edge of the centre section. The machine may have one or more engines which may be enclosed in or faired into the wing. It may have short underwings and a tandem wheel undercarriage. It may also have a hull similar to that of a flying boat for operation from water.

427,017. *Tube Motor Aeroplane.* Zimmerman, R., Getrudstrasse 99, Zurich, Switzerland. Dated July 10th, 1933. No. 19,520.

This invention concerns an aeroplane which possesses several tubes arranged longitudinally. The purpose of the tubes is to capture the current of air which is caused by the revolving propellers, to guide the same through the tube where there is no resistance and out of its end through an outlet offering also no resistance. The air exit is described as taking place through an orifice which is roughly of the cross section of a normal aeroplane tail. It is stated that by this system the swells of air are reduced to a minimum and that the air flowing through the tubes increases the carrying power, the stability and easy sliding of the plane.

Airscrews

425,649. *Driving the Propellers of Aircraft.* Bock, G. A., Alberton, Queensland, Australia. Dated March 19th, 1934. No. 8,542.

It is proposed to use the combination of a crankless motor and a motor with the usual crankshaft, an extension shaft from the latter passing through the shaft of the forum. Each shaft may carry a concentric propeller, or there may be one propeller which may be connected by clutch gear to either motor. A laminary motor is stated to be suitable for the crankless motor.

Armament

426,911. *Improvements in or relating to Devices for Reducing the Recoil of Guns on Aircraft.* Birkigt, M., Rue du Capitaine Guynemer, Bois-Colombes, Seine, France. Convention date (France), March 1st, 1934.

In this device, intended for use where a gun is fitted to fire through the propeller shaft, the barrel of the gun is normally extended by a flame protector formed by a tube having a larger bore than the bore of the gun. This flame protector extends forward of the propeller and carries a double-walled cone-shaped member. In the centre of this member there is a hole to permit the bullet to emerge, while the powder gases are constrained to pass between the walls of the cone, and are hence directed backwards. The powder gases, striking the forward wall of the cone, produce a reaction in the opposite direction to the recoil of the gun.

Control of Aircraft

423,709. *Improvements in or Relating to Head Wind Brakes for Aircraft.* Junkers-Flugzeugwerk Aktiengesellschaft, 40, Junkerstrasse, Dessau, Germany. Convention date (Germany), July 3rd, 1933.

This braking device is intended to be specially suitable for reducing the nose diving speed of an aircraft. It consists of a strip mounted on the underside of the wing and parallel to the span. The strip should extend over half the wing, should be fitted within the front 40 per cent. of the chord and should project from the wing to an amount not exceeding 6 per cent. of the chord. It may be operated manually or automatically, *i.e.*, operated by a mechanism which comes into use when the speed of the aeroplane exceeds a predetermined figure. It is claimed that the effect of the device is greater when the wing is at a small or negative angle of incidence. Several methods of constructing the device are described.

423,752. *Improvements Relating to Aircraft Controls.* Hawker Aircraft, Ltd., Canbury Park Road, Kingston-on-Thames, Surrey, and Camm, S., of the same address. Dated Oct. 16th, 1933. No. 28,599.

This specification describes a method of operating aeroplane controls, such as ailerons, by means of a mechanism which can be substantially contained within the thickness of the wing. The control cables are attached to a pulley which can therefore be rotated when the controls are moved. This pulley is fitted on a spindle carrying a crank which is connected to the aileron lever, which is approximately horizontal, by means of a link. A balance weight may also be incorporated. Several means of obtaining the same result are described.

423,565. *Improvements in Aeroplanes.* Boulton and Paul, Ltd., Riverside Works, Norwich, Norfolk. Dated July 20th, 1934. No. 21,265. Convention date (U.S.A.), Nov. 3rd, 1934.

It is pointed out that ailerons are effective for lateral control at small incidence angles of the wings, but become ineffective at large angles. It is therefore proposed to use a different method of control at large incidence angles, preferably combined with ailerons for use at small angles. This different method consists of a method of decreasing the lift on that side of the aeroplane which it is desired to drop by means of what is called a spoiler passage in the wing, the upper opening of which is forward of the lower opening. It is stated that at large angles of incidence there is a flow through this passage from below the wing to the upper surface which destroys the normal flow over the wing and also the lift. Various methods of opening and closing the spoiler passage are described, and methods are given by means of which the device may be combined with ailerons.

426,689. *Improvements in or relating to Aeroplanes, Seaplanes, or other Heavier-than-Air Flying Machines.* Jona, A., 14, Via Georgio Jan, Milan, Italy. Dated June 29th, 1934.

It is proposed to provide a hinge connection between the wing of an aeroplane and the fuselage so that the two systems are capable of performing independent rolling movements, the control cables of the ailerons being connected to fixed positions on the fuselage in such a manner as automatically to move the ailerons in the direction necessary to return the wing to its normal position. The hinging of the wing may be damped hydraulically or otherwise and/or may be controlled by a spring device and the top wing only of a biplane may be hinged, the lower wing carrying ailerons operated by the pilot in the usual manner. A method is described of overcoming propeller torque and the arrangement is claimed to provide automatic lateral stability.

426,439. *Improvements in Automatic Course Redresser for Aircraft.* Societa Anonima Sviluppi Aeronautici (S.A.S.A.), 184, Corso Umberto I, Rome, Italy. Convention date (Italy), Feb. 8th, 1933.

This apparatus is intended to control the rudder of an aircraft automatically and receives its indications from a compass or gyroscopic device, etc., from which appropriate electrical currents are transmitted to the apparatus controlling the rudder. This apparatus consists of three wheels mounted on the same centre: the two outer are rotated in opposite directions by an electric motor or other convenient means, while the centre carries a grooved rim which accommodates the rudder cables. Solenoid controlled pawls are provided working on ratchet teeth on the outer wheels so that the inner wheel may be coupled to either of the outer wheels so as to rotate with it. De-clutching mechanism is described and also a safety device to prevent both wheels being clutched in simultaneously.

425,645. *Improvements in or relating to Aircraft.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Lobelle, M. J. O., Langley Road, Langley, Bucks. Dated Feb. 14th, 1934. No. 4,928.

It is proposed to provide at the tail end of the fuselages of aircraft certain fins in pairs lying in the direction of the airflow for the purpose of assisting control during a spin. These fins may be fitted above or below the fuselage, may be of various shapes in plan form and their sections may be similar to those of aerofoils, or they may be symmetrical. The angle of convergence of the fins may be varied by mounting them so that they may be turned about longitudinal axes.

Engines

424,498. *Improvements Relating to Air-Cooling of Radial Cylinder Internal Combustion Engines.* MacClain, A. L., 1218, North Main Street, West Hartford, Hartfort, Connecticut, U.S.A. Dated Aug. 22nd, 1933. No. 23,331.

It is stated that it is possible to increase the cooling of air-cooled radial engines for aircraft by arranging baffles between the cylinders so as to block the space between the cylinders except for the space between the individual cooling fins. For the cylinders the type of baffle proposed consists of a shaped plate fitting closely to the cylinder and connected by a nut and bolt to a spring bridging the space between and behind the cylinders. The engine is shown fitted with a cowl of the Townend Ring type and it is proposed to use baffles of a similar type to the cylinder baffles for the cylinder heads, but in this latter case the baffles are preferably attached to the ring.

424,546. *Improvements in or Relating to Fluid-Reaction Propelling Apparatus.* Endres, H., 116, Kullerstrasse Solingen, Germany. Convention dates (Germany), Aug. 15th, 1933; Nov. 9th, 1933; April 3rd, 1934.

It is claimed that the efficiency of the usual helical propellers for aircraft is very poor and that the speed they impart is very low, it is therefore proposed to substitute a fluid reaction propelling device which consists of a main jet from which compressed air issues and which is surrounded by a nest of similar nozzles. The apparatus contains a piston which is operated partially by compressed air and partially by a vacuum produced in spaces communicating with the nozzles. It is stated that with this apparatus the relative wind is utilised very largely for producing thrust force.

425,031. *Improvements in and Relating to Variable Speed Gearing.* Cassaque, G. R., Parellon La Bouvreuil, Avenue Guynamar Cazoux (Gironde), France. Convention dates (France), Feb. 8th, 1933; March 27th, 1933.

This is a type of differential gear which is arranged to balance the torque of the propeller drive with that of the supercharger so that when variations in speed of the propeller shaft occur suitable corresponding variations will be obtained in the speed of the supercharger. The gear is of the sun and planet type with two sets of planet pinions which can be clutched so that the differential action may be stopped if the supercharger is not required. Modifications of this arrangement are described.

425,046. *Improvements in and Relating to Propulsion of Aircraft.* Stenning, G. A., 63, Queen's Park Road, Brighton, Sussex.

This specification describes a method of propelling aircraft by ejecting fluid from a jet. By this means a zone of low pressure is induced within the aircraft and propulsion is partially effected by means of slots in the wing of the machine through which air is drawn and partially by the reaction of the jet. It is stated that the manner in which a vacuum formed within an aircraft may be utilised to effect movement of the craft will present no difficulty to those skilled in the art.

423,719. *Cowlings for Air-Cooled Aircraft Engines.* Armstrong-Siddeley Motors, Ltd., and Reynolds, R., both of Armstrong-Siddeley Works, Parkside, Coventry, Warwickshire. Dated Feb. 3rd, 1934. No. 24,426.

This specification describes a modified form of Townend Ring intended to facilitate the cooling of air-cooled engines, usually of radial form, by directing the air flow on to those parts of the engine which require most cooling. The ring is of aerofoil form having an inner and outer surface and the rocker boxes are inside the ring. The inner side of the section is flat and is parallel to the cylinder fins. The space above the cylinder is consequently screened from the direct flow of air.

407,530. *Improvements in or Relating to Radiators for Aircraft Engines.* Ferlay, G., 66, Rue Pierre Larousse, Paris, France. Convention date (France), March 12th, 1932.

It is proposed to use as a radiator a casing conforming to the shape of the leading edge of the wing and having inside it a venturi-shaped passage in the divergent part of which the radiator is situated. The air inlet of the passage is on the leading edge of the wing, and the outlet is in the form of a slot on the upper side of the wing.

427,094. *Improvements in the Propulsion of Shafts.* Hurd, G., 12, Rhodes Terrace, Beddington Grove, Wallington, Surrey, and Triggs, C. S., 155, Stafford Road, Croydon, Surrey. Dated Aug. 16th, 1933. No. 22,857.

It is stated that one of the hindrances to the progress of aviation is the practice of connecting one engine to one propeller so that if the engine stops the propeller stops also. It is proposed, therefore, to drive aircraft propellers from several engines, so that if one of the engines fails it will be automatically cut out. The engines may be arranged radially round the propeller shaft, each driving a gear wheel gearing into the propeller shaft gear wheel, the drive being taken through free wheel clutches. Other arrangements may be used for the engines; they may, for instance, be coupled in line through a bevel gear box, so that a number of engines may drive a number of propellers where axis of rotation is at right angles to the engine crankshaft axis.

Flying Boats

422,982. *Improvements in and Relating to Water Stabilisers for Flying Boats.* The Blackburn Aeroplane and Motor Co., Ltd., and Rennie, J. D., both of Seaplane Base, Brough, Yorks. Dated Jan. 6th, 1934. No. 552.

The form of stabiliser described consists of two wing floats which may be of usual form held in position on each side of the hull by means of stub wing extensions which start from the upper portion of the hull and extend downwards towards the water. An air space under the stub wings is thereby ensured, and it is claimed that the arrangement assists the ventilation of the main step.

Helicopters

423,005. *Improvements in or Relating to Aircraft with Rotating Wing Systems.* Breguet, L., 24, Rue Georges Bizet, Paris, France. Convention date (France), May 27th, 1933.

The specification refers to gyroplanes of the type described in British patent No. 373,771 of March 21st, 1930, and has for its object the improvement of the autorotation effect produced when the engine stops, the autorotation being obtained by automatically reducing the incidence of the blades of the rotor under these conditions. The blades are carried by a short arm and are pivoted to it. When under power an angle is produced between this arm and the blades, but when autorotation occurs the blades and the arm are in a straight line. This movement, controlled by a mechanism, produces the alteration of the angle of incidence. The incidence regulator consists of an arm extending in a front-wise direction connected to a ring universally mounted with respect to the vertical shaft through a connecting rod disposed obliquely so that the angle it makes with the arm is less than 90°. A mechanism for the same purpose comprising toothed sectors and pinions is also described.

424,140. *Improvement Relating to Aircraft of the Gyroplane Type.* Jones, T., Cwmbach, Pontyates, Carmarthenshire, Wales. Dated Aug. 21st, 1933. No. 23,240.

The machine proposed is fitted with lifting rotors revolving on a horizontal axis and which are kept in rotation by the movement of the machine through the air. It is proposed to impart initial rotation to these rotors by belt or rope, driving them from the landing wheels. A further claim is concerned with the shape of the leading or trailing edges of the winged rotors, which may be deeply recessed or which may be formed of a succession of circular discs.

423,371. *Improvements Relating to Aircraft.* Flettner, A., Neue Bayreutherstrasse, 7, Berlin, W.30, Germany. Application date, Aug. 22nd, 1933. No. 23,355.

This is a helicopter aircraft in which the helicopter airscrew is capable of having the incidence of the blades altered, for control purposes, for lifting purposes, and also for autogyration. The incidence alteration is not necessarily the same for all parts of the blade and it may be effected automatically as the rotational speed increases. In this latter case the blades are mounted on a shaft on screwed collars so that as the blades move outwards under centrifugal force their incidence is altered, the outward movement being controlled by a spring. Separate steering blades may be used. Each blade is controlled by means of a lever at the hub by means of which the incidence may be controlled.

420,686. *Improvements in and relating to Gyroplanes or Helicopters.* Van Poelvoorde, P. J., 24, Rietzanger Lane, The Hague, the Netherlands. Convention date (Netherlands), May 18th, 1933.

This is a method of stabilising helicopter aircraft, which it is proposed to effect by forming the machine with two rigid units, the upper being the lifting unit and the lower the load-carrying unit. These are connected together by one or more flexible connections which are attached to the lifting unit at a point below its centre of gravity. Calculations are given which purport to show that there is produced by this arrangement a righting movement, when the lifting unit is tilted.

426,197. *Improvements in or relating to Rotative Wing Aircraft.* Coats, A. G., Gloucester House, Park Lane, London, W.1, and Hofner, R., Mantlergasse 47, Vienna 13, Austria. Dated Aug. 25th, 1933. No. 23,646.

It is proposed to provide mechanism by means of which a rotative wing aircraft may be flown either as a helicopter or as an autogiro, here called a windmill plane. The variation of the setting of the blades for the two methods of flight is to be obtained automatically and depends mainly on the speed of rotation of the blades. It is stated that at high speeds of rotation the dihedral angle is greater and by connecting the blades through a crank and connecting rod to a fixed point on the vertical rotating shaft this alteration of dihedral may be used to effect the alteration. A governor may also be used and also the deformation of a part carrying the main drive. A free wheel device may be interposed on the driving shaft or a clutch device actuated by a quick pitch thread.

Instruments

425,009. *Improvements in Directional Stabilising Apparatus for Aerial or Marine Craft or Navigational Instruments.* Schneider and Cie., 42, Rue d'Anjou, Paris, France, and Fieux, J., of the same address. Convention date (France), Dec. 1st, 1933.

This device is of the type comprising a combination between a gyroscopic direction mark and a servo motor acting on the rudder. The apparatus permits the instantaneous reading of the mean course and the rapid determination of the drift. The gyroscopic system of reference may be similar to the well known system utilised for the direction of torpedoes. There is combined with the usual distribution of the fluid an additional distribution for each side of the servo motor piston, these acting in series with the first distribution and coming into action by an action of the gyroscope exerted through the intermediation of a friction transmission between the vertical suspension frame of the latter and the movable members of the additional distributions under the effect of the change of sense of direction to which the vessel is subjected after the termination of each yaw.

425,964. *Improvements in Safety Indicators for Aeroplanes.* Shanley, F. R., 11, Prince George Avenue, Takoma Park, Maryland, U.S.A. Dated June 15th, 1933. No. 17,081.

It is claimed that an instrument indicating at any moment the stresses on the structure of an aeroplane would be useful for civil aircraft, and it is stated that the criterion necessary to accomplish this is the value of g which may be acting on the aeroplane at the moment combined with the pitot head reading. The instrument proposed has a weight supported by a spring which is arranged to extend under acceleration. This weight carries an electric contact which may make contact with a plate controlled by a corrugated pressure disc actuated from the pitot. The contact side of the plate is arranged to conform with a calculated curve, so that contact is made at differing accelerations at different pitot pressures. The current passed may light a lamp on the pilot's dashboard.

Kites

422,970. *Improvements in or Relating to Kites.* The Bias Bindings Co., Ltd., Gorgie Road, Edinburgh, Scotland, and Turner, J., of the same address. Dated Oct. 14th, 1933. No. 28,422.

The kite proposed is of a rhomboidal shape and is arranged so that the fabric threads are on a bias relative to the upright and cross members. At each corner a pocket is formed to receive the ends of the upright and cross members, the length of these being slightly greater than the corresponding dimension of the kite, so that they take up a curve when placed in position. The kite is flown with the convex side facing the wind and it is stated that the curvature provides stability in flight.

Miscellaneous

424,703. *Vehicle Collision Guards.* Nasbet, A., 6, Reynoldson Street, Sunderland. Dated Nov. 2nd, 1933. No. 30,414.

This specification refers to collision guards primarily intended for use on motor vehicles, but stated to be capable of adoption for aeroplanes. The cross bars at the back or front of the vehicle are carried by cylinders containing springs which absorb collision shock. There is a weak spring for slight shocks and a stronger spring which comes into action if a severe shock occurs.

426,385. *Means for the Control of Two-Way-Moving Devices such as a Ship's Rudder.* Martin, E. G., Travellers' Club, Pall Mall, London, S.W.1. Dated Oct. 4th, 1933. No 26,281/34. Divided out of application No. 27,289/33.

This specification describes a mechanism primarily intended for operating a ship's rudder. A steering wheel of normal design controls a winch which has drums of differing diameters. There are a pair of bights, the two ends of which are oppositely wound on the larger and smaller winch diameters respectively. Alternatively the drum may carry coned pulleys so as to alter the leverage between the wheel and the rudder as the angle of the latter is increased. The rudder wires are connected to the rudder through a spring shock absorbing device.

426,015. *A Wheel having Feathering Vanes adapted for use in Air or Water as a Motor or Propeller.* Sprigings, W. A., 59, Bernard Street, St. Albans, Herts. Dated Nov. 30th, 1933. No. 33,605.

This specification refers to feathering blade motors or propellers where a number of blades are caused to present their edges and their surfaces in sequence to their surrounding elements. It is proposed that the motor should have blades which substantially along their whole width terminate in anchorage with a disc or a shaped root and that the root should transmit axial motion to the blades.

Ornithopters

425,949. *Flying Machine with Oscillating Wings.* Eberhart, R., Engelburg, Switzerland. Dated Aug. 3rd, 1934.

It is proposed to connect the oscillating wings by a ball and socket joint to a common driving shaft and to have a pressure surface at right angles to the axis of oscillation, whereas supporting elements are fixed on the driving shaft which have a ball bearing surface obliquely intersecting the driving shaft and bearing against the pressure surface. Two reciprocating elements are provided for controlling the adjustment of the wings relatively to the longitudinal axes of the machine.

426,460. *Balanced Rotary Feathering Wings.* René de Tyron-Montalembert, Villa St. Christophe, Avenue Fernand Martin, Villefranche-sur-mer, Alpes Maritimes, France. Convention dates (France), July 18th, 1933; May 9th, 1934.

This specification describes a system of rotating blades for raising and propelling aircraft, which are arranged to be driven by toothed gearing in such a way that there is imparted to the blades a rotative movement round the main shaft and a movement round their own axes, means being provided for regulating the action of the blades on the air. There is a system of this type on both sides of the aircraft so that the action of one balances that of the other. In this way, for each rotation of the driving shaft, the simultaneous lowering and starting lowering of the two wings will also expel the air downwards on either side of the fuselage and the volume of air comprised between the descending movements of the two other wings continuing their rotation and before the retractive movement of the upward stroke will be violently pushed towards the rear and underneath the apparatus so as to produce a violent reaction similar to that produced by the simultaneous lowering of the two wings of a bird.

Undercarriages

424,265. *Improvements in or Relating to Brake Mechanism.* Elektronmetall, Gesellschaft mit beschrankter Haftung, Counstatt, Stuttgart, Germany. Convention date (Germany), Aug. 30th, 1932.

This device consists of a manually operated oil pump by means of which oil under pressure is produced. The oil is distributed to the braking devices on the wheels through a plug cock with passages so arranged that the braking may be equal in both wheels or differential as desired. This plug may be controlled by a connection to the rudder bar. The oil pump carries an additional cylinder which contains a piston moving in unison with the pump piston. This cylinder contains oil and is connected to the pump cylinder, its object being to ensure that the pump cylinder is always full of oil and to prevent the entry of air.

425,207. *A System of Retractable Landing Gear for Aeroplanes.* Société d'Inventions Aeronautiques et Mecaniques S.I.A.M., of 1, Route des Alpes, Fribourg, Switzerland. Convention dates (France), March 27th, 1934; May 9th, 1934.

This specification describes a method of raising and lowering a landing gear hydraulically. The gear is shown as pivoted at its upper end, and folding by rotation round this pivot, the actuating means being a hydraulic piston and cylinder operating on a crank pin. The fluid pressure is produced by an engine-driven pump, and the actuating piston and cylinder are double acting, the pressure on the reverse side of the piston being produced by a hydraulic reservoir with air pressure. The incorporation of this device enables the landing gear to be returned to its lowered position by hydraulic means. A special device is

included for the operation of trapdoors and a single lever control for the pilot is also described.

407,392. *Improvements in or Relating to Braking Systems for Aircraft.* Vickers (Aviation), Ltd., Pierson, R. K., and Duncan, T. S., all of Weybridge Works, Byfleet Road, Weybridge, Surrey. Dated Sept. 17th, 1932, No. 25,910, and March 2nd, 1933, No. 6,357.

This specification describes a method of compressed air braking for aircraft in which the pressure may be equally provided to the brakes on each side according to the will of the pilot, or differential braking can be done by means of a control operated by the rudder bar, or excess pressure may be applied to the brakes for parking purposes. In the latter case a separate valve box is provided, operated by an independent lever for opening a valve on the pipe direct from the air cylinder and closing off the rest of the mechanism. The mechanism for operating the brakes for landing consists of a lever operated by the pilot which acts on the inlet and exhaust valves through a spring-loaded diaphragm so that the pressure is applied in a servo motor manner, the greater the lever pressure the greater the air pressure, and hence the greater the braking effect. The connection from the rudder bar acts on a rocking lever and hence acts on the valves differentially.

426,134. *Improvements in or connected with Wheel Landing Gear for Aircraft.* Vickers (Aviation), Ltd., and Wallis, B. N., both of Weybridge Works, Byfleet Road, Weybridge, Surrey. Dated 28th Sept., 1933, No. 26,713, and 27th Sept., 1934, No. 27,715.

In the case of retractable chassis for aircraft, owing to the position which it is necessary for the wheel to occupy when the chassis is extended, it is difficult to arrange for the chassis to fold into the wing. In order to facilitate this it is proposed to arrange that the chassis, when folding, shall swing about two axes, one in the fore and aft direction, the other lateral. In one example of the proposed construction a supporting member mounted in a fore and aft direction in the wing receives the butt end of the wheel carrier member in the form of a fork in such a manner as to permit the fork to swing laterally from the extended position to the recess in the wing. A sheave, rotatably mounted on the tube, carries two spaced pivots for attachment of the butt end of the fork permitting the fork to swing backwards when caused thus to swing by a controlling member consisting of a cam or the like. The locking device comprises two pairs of diametrically opposite bolts which are adapted to engage with corresponding holes in the sheave and fork. Various modifications are described.

427,185. *Improvements in and relating to Landing Gear for Aircraft.* The Supermarine Aviation Works (Vickers), Ltd., and Dickson, R. S., both of Woolston, Southampton, Hants. Dated Oct. 17th, 1933. No. 28,707.

There is described a type of folding chassis, in which, in the case of a chassis designed to fold backwards into a wing, arrangements are made for the wheel to be turned approximately ninety degrees, so that it may be completely buried in the wing. The chassis consists of a post projecting downwards which carries the wheel and is pivoted at its upper end so that it can swing backwards. A rear diagonal stay is provided, the upper end of which slides on a diagonal rod in the wing. The upper end of this stay is thus moved sideways in the wing as the chassis is folded, and as the lower end is attached to the wheel which is pivoted, the wheel is turned to a degree depending on the angle of the diagonal rod. Applications to other types of chassis are described.

REVIEWS

Economics of Air Transport in Europe

By M. Henri Bouché. Published by the League of Nations. Price 3/6.

This is a report submitted to one of the sub-committees of the Organisation for Communications and Transit. The author is well known in aeronautical circles as the editor of *L'Aeronautic*.

The report contains a quantity of information about the various European air lines, much of which was collected under difficulties as in many cases there was obvious reluctance on the part of those interested to divulge the financial and other results attained. For this reason certain of the data may not be quite correct, but it is most unlikely that it can be so seriously in error as to vitiate the results.

There is no doubt that on the general results Imperial Airways appears very favourably. Taking the ratio between receipts from customers and State subsidy expressed as (receipts from customers/subsidy), an expression which is obviously equal to one where subsidy equals receipts, Imperial Airways had attained a figure of 1.8, the highest in Europe, Holland having a figure of 1.43, Finland 1.59, while certain countries such as Italy had a figure of 0.07. The utilisation of tonnage figures also differs largely. Imperial Airways' figure of 62 per cent. being the second highest in 1932, the highest figure of 66 per cent. being returned by Greece. Italy is some way down the list with 41 per cent.

The number of hours flown annually by the pilots of the various lines is also of interest. The highest in Europe belongs to the Deruluft, U.S.S.R. and Germany, whose pilots average 613 hours. The Imperial Airway figure is 540, and most of the larger European countries are round about this figure, though Italy is again low with 306. There seems to be something peculiar about Italian civil aviation which may be connected with government policy, which may again be associated with the use of civil aircraft which are unusually expensive to run. All these figures are much below the American, given by M. Bouché as 850 hours per pilot; this figure seems so high that it is difficult to credit. Has there been some confusion on the matter of machines carrying two pilots, whether the hours should be credited to one or both?

The Report contains a large number of charts and tables enabling nearly all the important features of air travel in the various countries to be explored and compared and the reading matter is well and lucidly written and there are many apt comments on the data. It is a publication which is essential to a proper understanding of air transport matters in Europe.

Planes Directory of the Aviation and Allied Industries

Planes Publishers, Ltd., 4, Johnson's Court, London, E.C.4.

This is a useful work of reference on matters concerning aviation. The commercial section gives a comprehensive list of firms dealing in aircraft goods; there is a list of brands and trade marks, and a list of aeroplane owners with their addresses. This is followed by a list of prominent people from which the names of the chairmen of the Royal Aero Club and the Air League are conspicuously absent. There is also a list of clubs, classified trades, air lines and aerodromes, etc.

The book contains a useful collection of miscellaneous information which seems to be accurate as far as it has been possible to check it, arranged in a way which is handy for reference.

Elements of Practical Flying

By P. W. F. Mills. Published by the Technical Press, Ltd. Price 4/6.

This book is intended to provide those interested in flying with a modicum of easily digested technical information. Such a scheme is admirable, as there is a lamentable lack of aeronautical knowledge among those who fly. Unfortunately Mr. Mills has only an approximate acquaintance with his subject, though he certainly knows something about practical flying; but this alone does not qualify him to discuss theoretical matters intelligently.

There are a number of curious statements in the book, among which can be quoted the suggestion that an aeroplane wing has the property of converting drag into lift and the use of the term "windmill aspect of the wings" which is defined as meaning that a relatively large area of wing surface is visible from immediately above the aeroplane. This vague term is supposed to have something to do with lateral stability. It also seems hardly necessary to record the fact that the boss of the airscrew plays no part in producing thrust. The book is too full of loose and wild statements of this type to be satisfactory for the purpose for which it is intended, for, although it is of unquestioned importance to increase the general knowledge of aeronautical technicalities, it is vital that the learner should be taught correctly.

The 586th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

A meeting of members of the Royal Aeronautical Society was held in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, on Thursday, 13th December, 1934, at 6.30 p.m., when a lecture was given by Dr. W. H. Hatfield, M.I.M.E., M.I.A.E., A.F.R.Ae.S., of Sheffield, entitled "Ferrous Metallurgy in Relation to Aircraft." In the chair, Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.P. (President).

The CHAIRMAN: Dr. Hatfield was really an old friend. He was Director of Research and Technical Development of Firth-Brown, Limited, Firth-Vickers, Limited, Vice-President of the Iron and Steel Institute, Chairman of the Heterogeneity Committee, which dealt with ingots, and Chairman of the Corrosion Committee. The last time Dr. Hatfield read a paper to them was in 1917 and the title was "Steels Used in Aero Work." Ever since then he had been indulging in research and development and it would be of extreme interest to hear what had occurred in those intervening years. It was certainly a great deal.

Dr. HATFIELD: Before reading his Paper he would like to say that his was a difficult task, inasmuch as he had about 50 minutes in which to present a survey of the results of his examination into the subject of the paper made since he received the invitation from the Society about six months ago. He hoped that they had all read the paper, with a view to subsequent discussion, and that any who might not have done so would be encouraged by the indications that he would give of its contents to go through it in detail.

Aeronautics was a most interesting and intriguing work, and metallurgists were very gratified at the reliance that was placed upon them by that branch of engineering. The confidence of the user in his material had never been brought home better to the lecturer than on the occasion when Colonel Lindbergh flew over here. It would be remembered that their Society and others joined in giving a dinner to Colonel Lindbergh at the Savoy Hotel, and he (Dr. Hatfield) would never forget the graphic way in which he described how, for something like 400 miles, he was flying blind over the Atlantic, but evidently he had complete trust in the material and the design of his plane. Another intriguing moment for the lecturer was when, sitting next to Miss Amy Johnson, he heard her describe her original flight to Australia. It was those little incidents which added spice to their somewhat tedious but interesting work of investigating metals in the laboratory.

FERROUS METALLURGY IN RELATION TO AIRCRAFT

BY

DR. W. H. HATFIELD (Sheffield)

Nearly twenty years have passed since the author had the pleasure of giving a paper on the same subject* to this Society. Progress in the meantime as regards the means and art of flying has been not only sustained, but rapid, as is brought out by the simple facts contained in Table I. The amazing technology is well represented by the De Havilland Comet, which has just flown to Australia and back in thirteen and a quarter days, developing 460 h.p. with a weight ratio of 12lbs. per h.p. It therefore becomes interesting and perhaps useful to determine the extent to which metallurgy has contributed and is contributing.

It is proposed to confine this paper to Ferrous Metallurgy, since that is the field with which firstly the author feels most qualified to deal, and secondly, because steel, in a manner unparalleled amongst available metals, can be so profoundly modified in properties by changes in composition and heat treatment. The soft base metal iron becomes, at the will of the metallurgist, hard, of great strength, highly magnetic, non-magnetic, rustless, of abnormally low coefficient of expansion, can have conferred upon it a capacity for thermal expansion equal to aluminium alloys, and withal is confirmed in a soundness and reliability not approached by other structural materials. It is true that throughout these various forms and conditions its modulus of elasticity varies comparatively little and small hope can be given of substantial modification, but if the ratio of specific gravity to proof stress or maximum stress is considered, it is found, see Table II, to maintain the lead in usefulness.

The author's old friend, General Bagnall Wild, who was responsible for the 1917 paper being given, then commented in the discussion, with much truth, that five steels would meet 75 to 80 per cent. of the requirements of the Air Ministry. Quite a number of new steels have been devised in the meantime, and the present position is brought out in the schedules of current specifications contained in Appendix II. The need for restriction in the number of steels employed is, however, as necessary and desirable as it was then. The Air Ministry has, however, quite rightly left open wide the gate for the admission of any steel into service whereby greater efficiency could be achieved.

Ferrous metallurgy, whilst having iron as its base, yet owes its importance to the influence of the carbon upon the structure and properties of the metal, not only in the simple binary iron-carbide system, but particularly when other added elements are present. Small quantities of added elements, particularly in the heat-treated condition of the steel, result in changed mechanical properties due mainly to the form, size, and manner of dispersion of the carbide in the iron matrix, but large quantities of certain elements in certain cases, resulting in retaining the carbide in solid solution, profoundly change also the physical and chemical properties. Thus great play can be made with the various combinations which are possible with the other alloying elements. There is great work in front of metallurgists to explore adequately the almost unlimited possible permutations in the various systems which can be envisaged. The last twenty years have already seen substantial new achievements, and entirely new steels are already employed in your field. The author has, from time to time, had

* Steel used in Aerowork, 1917.

great interest in reviewing the possibilities of technical progress as regards the application of such new ferrous products.*

Great progress has been made in other directions. The physical chemistry and general conditions of steel making are more completely understood and cleaner steel is now made: steel freer from non-metallic inclusions.

The casting of ingots has become more of a science, the work of the Heterogeneity Committee of the Iron and Steel Institute having thrown much light on the manner of freezing. Liquid steel, being a complex solution of many elements, or their compounds, in iron, freezes differentially and therefore the mere crystallisation during solidification does produce heterogeneity of marked degree unless the various factors, such as condition of the steel, mould design, casting temperature, and speed of teeming, are adequately controlled. Understanding as regards these factors has resulted in much more homogeneous steel than was obtainable years ago.

Again, the hot working (forging and rolling) is now performed in the optimum ranges of temperature, when the steel best lends itself to such deformation. Incidentally, much advantage is taken of the effect of forging upon the layout of the structure, *i.e.*, the orientation of any residual non-metallic inclusions and their accompanying effects within the steel. Thus can the layout of the structure be arranged with every consideration to the direction of maximum stresses.

In the field of heat treatment, *i.e.*, softening, hardening and tempering, etc., great knowledge has been obtained as the result of researches by many investigators at home and abroad.

A word must be said concerning inspection; this is indeed extremely meticulous. It is realised that the smallest irregularity or defect may be the predisposing cause of failure in the finished part. Such is the care taken in the case of master and articulated connecting rods, gudgeon pins, cylinder barrels, etc., that the material is lightly etched in order that any " microscopic " flaws may be detected.

The net result is that you may reasonably expect a very high standard to-day in aeroplane parts. Every encouragement is given by the A.I.D. and their system to the incorporation of every form of advanced technique. And here a word may be said from the economic side. Whilst everything in the way of quality is expected, those concerned do not demur at any reasonable cost involved. The author and his colleagues have been constantly concerned in these matters, and it is a source of gratification to have the opportunity for making these observations to the members of your Society.

This attempt to review the steels in use, and available, would be impossible without rather extensive data, which the author has collected with the resources at his disposal. This data consists essentially of:—

Schedule of steels at present specified (see Appendix I).
The application of steels to different parts (see Appendix II).
Mechanical test data concerning selected typical structural steels (see Table III, pages 576 and 577).
Physical properties of selected typical structural steels (see Table IV, pages 578 and 579).
Mechanical test data concerning selected typical rich alloy steels (see Table V, pages 580 and 581).
Physical properties concerning selected typical rich alloy steels (see Table VI, pages 582 and 583).
Heating and cooling curves of typical steels (see Diagram 2, page 572).
Microstructures of typical steels (see Plates, pages 566-572).

* " The Most Suitable Steels for Automobile Parts," Proc. Inst. Auto. Engineers, 1920, XIV, p. 503.
" Further Notes on Automobile Steels," Proc. Inst. Auto. Engineers, 1921, XV, p. 465.
" Steels for Automobiles and Aeroplanes," Proc. Inst. Auto. Engineers, 1929, XXIV, p. 81.
" Rustless Steels and Aircraft," Proc. Inst. Auto. Engineers, 1931, XXV, p. 285.

Safety in Design (Proof Stress and Fatigue)

The choice of the material for a particular part has to take account of (*a*) strength for weight, (*b*) reliability, (*c*) suitability for forming into the desired shape by the particular method to be employed. Reliability requires complete freedom from defects, and is determined in the main by ductility and by lack of any tendency towards brittleness. The order of ductility required varies with the nature of the duty the part is called upon to perform. In particular we have to consider how far during fabrication or in service it is liable to be called upon to withstand deformation stress or shock other than those inherent in its normal steady duty.

The highest stress in service should be below the true elastic limit of the material in order to avoid " permanent set." The Air Ministry has of late years wisely pursued the policy of basing the characteristics of steel supplies to a large extent upon the " proof stress values," corresponding to 0.1 per cent. of permanent set.

Such a value is the nearest practically determinable approach which appears to be commercially possible to a true elastic limit, and although the testing methods to determine proof limits are by no means ideal, experience has now established such tests on a reasonably satisfactory basis.

Many parts of engines and aircraft are, however, subjected to " alternating stress." Failure might, therefore, occur by fatigue if the latter value is not taken into consideration in the factor of safety. The breakdown in a fatigue failure generally occurs without measurable deformation, and in such cases the determination of proof stress cannot be taken as a guide in this respect.

The data given in the Tables III and V show both the proof stress and the fatigue range; " proof stress " and fatigue limits do not run parallel to each other in the different types of steel. In general, the higher the tensile strength, the higher becomes the ratio of proof stress to maximum, but at the same time the ratio of " fatigue limit " to maximum (for reversed stresses with mean stress zero) decreases. Thus steels of 80/100 tons per square inch tensile strength with a fatigue limit ratio of say 40 to 45 per cent. have proof stress ratios approaching to 90 per cent., whereas a steel of 30 tons per square inch tensile has both these ratios approximately 50 per cent.

The old method of designing to a factor of safety based on ultimate strength was unconsciously not far removed from the later principle of designing on fatigue limit, since the ratio of these quantities is not greatly changed for various steels. The strength of any part should naturally be looked at from both points of view, *i.e.*, according to the greatest applied stress and the order of the alternating stress, which is operative, suitable strength being provided for both features, and with suitably selected factors of safety. It is clear, however, that for certain units, *e.g.*, vibratory and reciprocating parts, subject mainly to alternating stress, the development of a very high proof limit may not lead to a definite advantage.

There is still much to be learned about the behaviour of materials under pulsating stresses, complex stresses, and so on, and the exact criterion of safety under such stresses. We look forward to the publication of further data on these subjects by Dr. Gough and his collaborators at Teddington, and our friends at Farnborough and elsewhere, as such information is necessary for further help in the more economical use of metal in aeroplane parts.

The author and his colleagues are intensely interested in this phase of matters. Generally speaking, design, stated empirically, seems to be based on stressing to two-thirds of the proof stress in tension or one-half of the maximum stress in tension; it being understood that the calculation of the maximum imposed stress takes note of every conceivable additive abnormal or accidental factor. The author would go so far as to state that with the present reliability of the material and the extending knowledge of its capacity for resisting permanent deformation, the factor for " ignorance " from this point of view can

be definitely less than from the standpoint of the knowledge of stress set up by the forces applied in service. A word might be said concerning the author's frequently expressed view that design is better based as regards factor of safety when the materials employed are not in an excessively hard condition. Clever calculations based on high values may result in an adequate paper factor of safety which does not actually exist in practice. It is his opinion that adequate ductility must exist for safety in all highly stressed parts.

Progress in Ferrous Metallurgy Since 1917

As regards steels and steel alloys, since 1917 there has been the introduction of more than a dozen *new types*.

In referring back to aircraft specifications one could count in 1917 about 35 different specifications covering about a dozen types of steels. To-day Air Ministry specifications number nearly 100 covering about 30 different types of steels. Outstanding amongst these are the newer types of stainless steels about which more will be said later.

By reference to the list of specifications which the author has attempted to put in logical order in Appendix I to the paper, the following changes as regards ferrous alloys might be mentioned:—

Carbon Steels

There has been little change except in quality and reliability as regards these steels. The range of carbon contents is very wide, and provides for many different purposes from the dead soft material suitable for deep pressing (*e.g.*, water jackets) to the high carbon steels such as that used for high tensile wire for valve springs. Cylinders made in 0.55 per cent. carbon steel demand a high standard of uniformity and cleanliness. It is usual to accept such steels on micro-examination, this ensuring a sufficiently high standard of cleanliness.

Low Alloy Steels

Increasing use is being made of steels containing about 1.5 per cent. manganese and a small percentage of molybdenum, for such items as tubes and plate fittings where a medium high tensile condition is demanded, adapted for ease in welding; in bar form (D.T.D. 188) this steel has good mechanical properties. The 3 per cent. nickel steel formerly used as a 45-ton heat-treated alloy steel has been to some extent superseded by a slightly modified composition heat-treated to give a minimum of 55 tons per square inch tensile strength.

Low chromium-molybdenum steels are finding use as tubes of 45 tons per square inch tensile strength, whilst a higher alloy type of chromium-molybdenum steel containing a small percentage of nickel is finding use as an alternative to the higher tensile alloy steels of the nickel-chromium and nickel-chromium-molybdenum types.

High Tensile Alloy Steels

Greater service for highly stressed structural parts such as crankshafts, connecting rods, etc., has been made possible by the use of modifications of the usual $3\frac{1}{2}$ per cent. nickel-chromium steels. These modifications have included additions of molybdenum, vanadium, etc., and up to 70 tons per square inch tensile strength, with high ductility and impact value, as well as high yield ratio are consistently obtained. It should be stated that such steels demand the best knowledge of the steel maker both in manufacture and manipulation. The same remarks apply to the alloy steels employed for still higher tensile strengths such as the air-hardening nickel-chromium steels, chromium-vanadium steel used for valve springs, and the case-hardening nickel-chromium steels.

Case-hardening Steels

For parts where a hard wearing surface is demanded in combination with a highly stressed tough core, as, for example, in a number of engine details, camshafts, rockers and small gears, the carbon case-hardening steel has largely given way to case-hardened alloy steels. Two per cent. nickel case-hardening steel has been replaced by 3 per cent. or 5 per cent. nickel, and the high tensile case-hardening nickel-chromium steel is used where a very high tensile core strength is demanded. The latter steel is very suitable in many situations where surface hardness is not required, since as a straight heat-treated steel it ranks very closely in tensile strength behind the air-hardening nickel-chromium steels, and where a little greater toughness is required than the air-hardening variety gives, the combination of 85 tons per square inch minimum tensile strength with 12 per cent. minimum elongation, and high notched impact value, offers scope for further applications in weight saving of highly stressed parts.

The 100/110-ton tensile air-hardened nickel-chromium steel combining high tensile properties with simplicity of treatment and suitable for many other parts besides gears, is not normally case-hardened, but can be so treated if desired.

Nitriding Steels

The process of surface hardening certain classes of steel by introducing nitrogen into the surface was put into commercial applications in recent years. The advantages of the method consist in the production of a superhard thin skin by a process which is free from the difficulties attending ordinary case-hardening, *i.e.*, risks of cracking and warping which usually entail a certain percentage of wasters, and always demand a finishing operation such as grinding for removal of the irregularities and allowances which consideration of warping and scaling made necessary. The nitriding operation carried out at comparatively low temperatures permits of parts being finished to exact dimensions, and except for slight cleaning up no further work is necessary after surface hardening.

The base material on which this operation is carried out is generally the special aluminium-chromium steel developed for the purpose. The D.T.D. specification, No. 87, covers this type of steel, and it is a useful property that this steel can be hardened and tempered like other alloy structural steels, giving a range of useful conditions of tensile strength, and further that these properties once attained, giving a machinable condition, are not in any way modified as regards the core material during the subsequent surface hardening. These steels, known as " Nitralloy " steels, are made with different carbon contents according to the ultimate strength required in the core.

Other steels are used for " nitriding," such as chromium-vanadium steel and chromium-molybdenum steel (low nickel). These latter do not give such an intensely hard skin as the aluminium-chromium steels, but this is an advantage for certain applications, since naturally the less hard skin is less liable to be " flaked " under intense local pressure. Ordinary carbon or alloy steels do not respond appreciably to the nitriding treatment.

Mention should be made of the interesting work of Mr. Sutton and his colleagues at the Royal Aircraft Factory on the nitriding of austenitic and allied steels. The nitriding of the surface is shown to be facilitated by a previous deposition of a thin layer of copper.

Valve Steels

The subject of aero and auto engine valve steels has been discussed very fully in several recent papers, notably by J. R. Handforth (Journal Iron and Steel Institute, 1932, No. 2, pp. 93-157). Heat-resisting properties, both as regards strength when hot and resistance to scaling under the influence of exhaust gases, is specially demanded in order to maintain efficiency of operation of the valves over a useful working life.

In 1917 the only special steels considered for this duty were the plain high chromium steels. As a result of much experimental work it now appears that one or other of the austenitic chromium-nickel-tungsten steels covered by specification D.T.D. 49A. offers the best range of usefulness. Certain of these steels, in addition to their heat-resisting properties, have also the advantage that they can be surface hardened on the wearing parts by the nitriding operation mentioned above. The valve question is still very much alive, and it cannot be said that the problem has yet reached a final solution. The high thermal expansion of most of the austenitic steels, necessitating large clearances, and also the comparatively low thermal conductivity, are disadvantages of such steels.

High Thermal Expansion Steels

There are a number of items in engine construction where steel is required to work in conjunction with light alloys, for example, cylinder head bolts and studs, valve seatings, cylinder liners—the steel providing strength or abrasion resistance at the operating temperature or other properties which the particular part demands, whilst the adjacent light alloy avoids the inclusion of undue weight. The comparatively high thermal expansivity of aluminium leads to looseness or difficulties in fitting unless the steel unit operating in conjunction with it has a very similar rate of thermal expansion. A type of steel which we had developed in another connection has been found to fulfil these requirements. This steel is an austenitic nickel-manganese-chromium steel, having a thermal expansion of 0.000021 per 1°C. up to 400 or 500°C., and combines good mechanical properties and resistance to abrasion. It is somewhat tough as regards machining, but this does not appear to be a special difficulty. Cold rolled austenitic chromium-nickel steel is an alternative material.

Other new materials which have been introduced since the date of the author's previous paper are the new powerful cobalt magnet steels or alloys with reference to the still newer nickel-aluminium alloy, both inventions being due to our Japanese friends.

Carbide Cutting Tools

This is an astonishing development worthy of every attention but outside the scope of the present paper.

It is now desirable to pass on to the stainless materials.

Developments in Stainless Steels Since 1917

In 1917 the only stainless steel available for structural use was the plain chromium type of steel as used for stainless steel cutlery. High nickel steels of 25 per cent. and higher were known, and whilst they were of value in a different connection, *e.g.*, non-magnetic properties, they have at no time been considered as suitable for structural purposes, partly on account of cost.

The limitations of the 14 per cent. chromium steels were undoubtedly a serious handicap. The author remembers being asked at the 1917 meeting, " What was the possibility of a cold drawn high tensile stainless material?" The 14 per cent. chromium steels had their corrosion resistance substantially reduced whenever cold working was carried out and, moreover, in the ductile condition used as a starting point for cold working, the corrosion resistance was already not up to the performance demanded for marine atmospheres.

Since that date has been seen the development of the stainless irons, the high chrome-low nickel steels, and the austenitic chromium-nickel stainless steels. There are now stainless steels for every purpose so far as structural steels go.

The degree of resistance to corrosion has been enhanced to a remarkable degree. The 18/2 (18 chromium/2 nickel) type of steel is practically resistant to sea water, whilst the 18/8 (18 chromium/8 nickel) type is completely resistant as

long as the surfaces are kept reasonably free from deposits. The steels can be formed to all manner of shapes, and perfectly satisfactory welding properties are now possible. The temporary difficulty due to " weld decay " effects has been completely overcome, although the troubles which arose in this connection have left their mark in the Air Ministry specifications in the form of the special corrosion test or disintegration test employing $CuSO_4.H_2SO_4$ reagent, the introduction of which was the result of researches in our laboratories in Sheffield in 1927. The further question of contact corrosion has now been brought to a fairly satisfactory stage. This question will be referred to later.

The stainless steels now available range from below 30 tons to above 100 tons per square inch tensile strength, and are obtainable in almost any form or size.

Properties of Stainless Steels

The characteristic features of the various types of stainless steels are now fairly well appreciated. The low carbon and medium carbon 14 per cent. chromium steels are capable of being hardened and tempered, the latter being capable of serving for the high tensile conditions with sufficient ductility to avoid premature breakage on bending or, alternatively, when softened to a tensile strength of about 45 tons/sq. in. The lower carbon type, more usually known as stainless iron, naturally hardens much less intensely, and is generally employed in a fairly soft and malleable condition. The quality of steel which has been adapted to meet the specification D.T.D. 46A. is really intermediate between the two types mentioned, having a carbon content of the order of 0.18 per cent. In the form of thin strip this material has air hardening properties permitting the attainment of a little over 80 tons per square inch tensile strength, and if the air hardening is followed by a very light tempering a substantial ductility is obtained.

High chromium steels with a sufficiently low carbon content are " ferritic," *i.e.*, they have no change points, and are non-hardening when quenched from a high temperature. The 18 per cent. chromium irons which come in this class have a tendency to brittleness, but by the inclusion of a moderate percentage of nickel—normally about 2 per cent. with a carbon content in the region of 0.1 per cent.—they are again in the martensitic or hardening class of steel. Specification S.80 is based on this type of steel, and with minor modifications the same steel meets a number of other specifications for sheet and bar, *e.g.*, D.T.D. 146, D.T.D. 168 (high tensile) and D.T.D. 225. In passing, it should be noted that *D.T.D. 185A. is formed so as to permit* an extremely low percentage of nickel—*i.e.*, may include a 16 per cent. chromium stainless iron. Such a material may involve some risk both as regards corrosion resistance and mechanical properties in comparison with the higher chromium low nickel material, unless very great care is exercised. The high chromium high nickel steels based on the 18/8 composition being austenitic and non-hardening demand a different technique, the chief characteristics of which are softening by high temperature treatment and hardening by cold working.

The corrosion resisting properties of the three types of steels show definite differences, the higher chromium conferring increased resistance, and the extra nickel making the resistance more general over a wider range of influences. Reference might be made to the data given in the Second Report of the Corrosion Committee of the Iron and Steel Institute, published early this year. The graph (Fig. 19, p. 205 of the Report), reproduced in Diagram 1, illustrates in a marked manner the general resistance of the various steels to atmospheric conditions, salt spray and acid spray respectively.

Details of the steels are given in the Report, but it might be stated here that numbers 2-12 are ordinary carbon and low alloy steels, numbers 13, 14, 15 and 16 are 14 per cent. chromium steels of varied carbon content with usual heat treatment, number 17 is a steel of the S. 80 type, numbers 19-22 are austenitic

chromium-nickel steels, and number 23 is a chromium-nickel-tungsten valve steel. The superiority of these latter to the varying corroding influences mentioned is clear. Steel number 18 is the 8 per cent. chromium-silicon valve steel which, so far as corrosion is concerned, does not show up very well. The other materials showing good corrosion resistance, numbers 26 and 28, are 15 per cent. silicon alloy and the nitrided aluminium-chromium steel respectively.

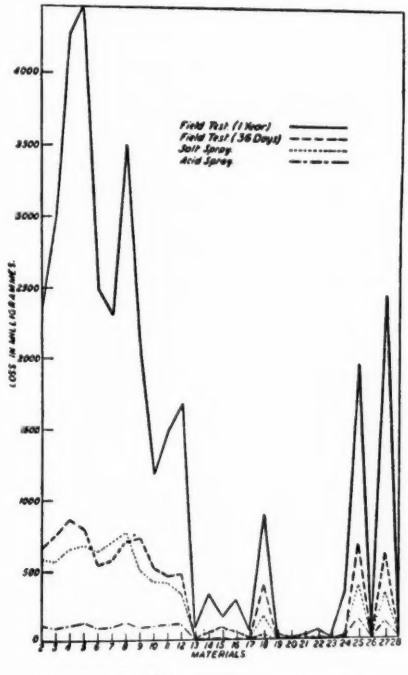


DIAGRAM 1.

Comparison of the Results of the Field Tests and Spray Tests.

Welding Properties

Oxy-acetylene and electric methods of welding are applicable in *some measure* to all types of stainless steel. The welding operations demand not only experience, but a due appreciation of the properties of the steels. Some of the special features are :—

1. When using oxy-acetylene, there is a liability for the weld metal to pick up carbon from the flame. The consequences are twofold—hardness of the weld metal and accompanying brittleness, and at the same time a reduction in corrosion resisting properties. A correct adjustment of the flame as regards proportions of oxygen and acetylene will avoid this trouble, but the warning is necessary since the same precautions are not so essential with ordinary steels. The flame should be practically neutral, with just the " slightest possible feather " of acetylene showing to act as a tell-tale of the proportions of the two gases. Too little acetylene, *i.e.*, too much oxygen will lead to a spongy weld.

2. The plain chrome steel, and the S. 80 type of steel, are liable to air harden on removal of the source of heat. This applies both to the weld metal and the metal immediately adjacent which has been raised to hardening temperature. This air hardening involves serious risk of cracking, especially when, during cooling, contraction stresses are set up. Re-treatment after welding is essential. Even this, however, will not induce ideal ductility into the weld metal itself, which is virtually a cast metal. This low ductility of weld deposit applies particularly to S. 80 and high carbon-chromium steels.
3. The weld metal applied by electrode or as filler rod should be similar to the metal welded. Alternatively, a deposit of an austenitic weld metal may be used such as D.T.D.61.
4. When welding parts of fairly high tensile strength, whether induced by heat treatment or cold work, the effect of the heating on the material slightly removed from the actual joint, should also be appreciated. A softening is produced in those parts raised to a temperature which corresponds to tempering operations. In a finished part this would mean a reduction of strength, hence the desirability in the case of hardened and tempered parts for re-heat treatment.
5. When welding austenitic steels the deposit, when cooled from the high temperature will, or should, be soft and malleable. The material at a little distance away, parallel to the weld, may have suffered " carbide separation," and if the steel is not of the disintegration proof type, may on subsequent exposure to corroding conditions suffer local intercrystalline corrosion or weld decay. Immediate re-heat treatment after welding will avoid this, but it is preferable to use the type of steel which is disintegration proof, and so avoid the danger (D.T.D. 111A., 176A., 166A.).

   Such local effects are not so liable to occur with short time heating and cooling such as is obtained with spot and seam welding, but even here there is some risk unless the correct steel is used.

   The methods employed by steel makers in order to obtain austenitic corrosion resisting steels free from the possibility of disintegration effects need not be discussed here.
6. After welding, the local contraction effects set up serious stresses, whatever the type of steel used. In dealing with complicated shapes, re-heat treatment to eliminate such stresses is advisable.
7. Distortion occurs both in heating and cooling during welding. Experience is necessary with different forms and types of jobs to employ the best procedure so as to keep this at a minimum. The austenitic steels have the greatest expansion and contraction, and are therefore most liable to distortion.
8. Correct choice of sizes of welding rod and speeds of operation are necessary to give correct penetration, etc. A suitable flux is helpful.
9. Complete cleaning of welded parts is necessary to avoid local corrosion effects. Slags or fluxes should be thoroughly removed, and any pickling acid should be also completely washed away.

Machining

In the early days, the peculiar work hardening properties of austenitic steels gave rise to machining troubles. The importance of sharp tools, and such details as keen rake angles, and avoidance of rubbing, are now fully appreciated and the difficulties have practically disappeared. Certain qualities, *e.g.*, the harder heat resisting austenitic steels, are naturally less easy to machine and demand reduced speeds and feeds.

Contact Corrosion

When metals of different kinds are in contact and any liquid which can serve as an electrolyte is present, conditions are obtained which can cause electrolytic corrosion. Owing to the different solution pressures of the two metals, electric potentials similar to those operating in an ordinary voltaic cell exist, and one of the metals is liable to be attacked. The subsequent behaviour depends very much on the nature of the reaction products.

Some experimental work on this subject carried out in our laboratories will be of interest. Couples were made by forming a thread on the end of a cylindrical sample of one material and screwing it into a threaded hole of a cylinder of another material. The various combinations were examined for their behaviour in sea water. Materials used included ordinary steels, stainless steels of all types, copper and copper alloys, bearing metals, aluminium and alloys, solders, etc.

It is not possible here to give full details. The method of suspension avoided contact with the glass containing vessels. In each case the sea water used for a test was entirely replaced every seven days, tests being continued for a month at normal temperatures.

It was found that contact of stainless steels and mild steels produced no measurable effect on the stainless steels and a slight increase in the corrosion of the mild steel, the increased attack on the mild steel being more marked in contact with the steels of greatest corrosion resisting properties. Copper and phosphor-bronze in contact with various steels caused increased attack on most materials, including 14 per cent. chromium stainless steel, the copper and phosphor-bronze themselves being protected. Increased attack on 14 per cent. chromium stainless steel was also induced by contact with silver solders and copper-nickel alloys. Contact of brass and copper with 18/8 and 18/2 caused increased attack of the copper bearing materials.

Duralumin was found to be considerably protected by contact with mild steel, but in contact with the stainless steels the effect was not marked either way, although a kind of streaky effect was noted in the Duralumin after test, presumably related to its macrostructure. It is to be noted that similar streaks occurred on the Duralumin when tested alone in sea water without contact with other metals.

Contact of one kind of stainless steel with another, *e.g.*, 18/8 chromium-nickel steel with 14 per cent. chromium steel caused appreciable increase in corrosion of the latter. A similar effect was obtained with S. 80 steel in contact with 14 per cent. chromium steel. Steels of the S. 80 and 18/8 type in contact showed practically no effect.

These tests are interesting in the light of the fear expressed that stainless steels in contact with aluminium alloys in service would cause considerable increase in the corrosion of the latter. The author has made mention later of machines constructed for sea conditions, having austenitic stainless steel bottoms in conjunction with Duralumin plating above the chine line, which have now seen about four years' service without damage from this cause. In any case, it is a comparatively simple matter to arrange for some separating medium such as paint, dope, or varnish, or better still, an electrolytic protecting metal such as zinc, to protect both the steel and the aluminium alloy. The troubles previously reported were possibly due to exceptional conditions. Perhaps some members of this Society may be able to contribute information on this point.

Internal Stresses and Corrosion Stress Cracking

There are a number of processes employed in fabrication, particularly with sheet materials, which are liable to leave the parts concerned in a state of internal stress. Any cold pressing or cold forming operation is liable to do so, and the amount of such residual stress will naturally be greater—other things being

equal—the greater the yield strength of the material in its deformed condition. The cold working operations combine plastic and elastic deformation, and after release of the deforming forces, the " elastic " component tends to relieve itself by a springing back of the portion of material concerned. In nearly all cases there is some restriction against this elastic recovery imposed by the neighbouring parts of the material, and a state of internal stress results. The examples of cold drawn tubes and of a spun cup-shaped article, left in a state of " tending to open out " to different diameters, but prevented from doing so by the continuity with the neighbouring material, are quite familiar. When a portion of such an article in the form of a thin ring is separated from the main piece and " split " at a point in the circumference, a large amount of elastic inward or outward springing of the split-ring is frequently found to occur. The phenomenon of season cracking in brass is known to be largely based on internal stresses of this type in conjunction with some corroding influences.

Productions made from sheet steel are liable to similar action, and stainless steels cannot be exempted from such a tendency. The residual internal stresses may be very high. One example brought to the author's attention was a tubular member in which the sheet after folding did not completely maintain the closed tube shape. When assembled along with its neighbouring parts of the complete structure the tube was caused to close and be held in that position. Owing to the thinness of the strip being used, the closing together did not involve very great force, and yet the stress involved was nearly 20 tons per square inch. The opening was about 0.2in. on a tube of 24 gauge thickness just under 1in. diameter.

It should be remembered that stresses of this kind are additional to the service stresses, and they are apt to be ignored in calculations when designing. The particular part mentioned had split after a period and there is little doubt that the extra stress from this cause, probably also helped by corrosion effects, had been responsible.

Another case where a similar type of stress may be introduced is round rivet holes. This is most liable to occur when the plates being riveted are somewhat thin, and the rivet is allowed to swell substantially on the shank during the closing operation.

It is perhaps also not sufficiently realised that the simple operations of punching and shearing can leave similar stresses. Shearing (especially if the shears have been allowed to become blunt) causes a squeezing in of the material near the cut edge, and as the shearing proceeds along the cut, the squeezed in portion is caused to stretch lengthwise, and then partially recover. The recovery is, however, only partial, due to the constraint of the material behind, and the result is that the thin band so compressed is left in a state of tensile stress acting lengthwise parallel to the cut.

The machining, grinding, reamering, or filing up of sheared or punched edges is therefore seen to be of importance, not merely to remove roughness, but also to remove the stressed zone. Residual stresses from welding operations are also very serious.

It is recognised that stressed zones may in certain situations arise under conditions where their removal is not practicable. The influence of stress on resistance to corrosion, and the influence of corroding conditions on resistance to stress is important. Corrosion fatigue has been much discussed in the last few years,* but the older phenomenon of combined corrosion and direct stresses is under some conditions even more important.

The following laboratory experiment will be of interest:—

Two pieces, 2½in. square, were cut from high tensile stainless steel strip of two different qualities. Erichsen impressions were put on these four samples and, recognising that this left the samples in a state of internal stress, they were

* H. J. Gough, J. Inst. Met., 1932, No. 2, pp. 17-92; H. J. Gough and D. G. Sopwith, *ibid.*, pp. 93-122; and J. Iron and Steel Inst., 1933, No. 1, pp. 301-335.

immersed in a solution designed to cause accelerated corrosion. The solution was 50 per cent. HCl. cold, and the pieces were left overnight. Numerous small cracks developed in two of the samples. Similar results were obtained by a short period—half an hour or so—in hot acid. It was seen that in addition to the main radial cracks round the central dome of the test piece there were a series of fine cracks round the sheared edges—corresponding to the stresses already described.

It is interesting to note that of the two high tensile materials mentioned—D.T.D. 46A. (14 per cent. chromium steel) and D.T.D. 168 (18 per cent. chromium, 2 per cent. nickel steel), both having 65 tons per square inch proof stress, the 14 per cent. chromium suffered serious cracking whilst the 18 per cent. chromium, 2 per cent. nickel steel, was *free*. Whilst it does not follow that the latter material would be free for all corroding conditions, it definitely shows superiority for severe conditions of this type. We have reason to believe that the plain 14 per cent. chromium type of steel can be affected in the way described, after *long* exposure to sea water conditions. Similar tests made on samples of the austenitic-chrome-nickel steels showed no signs of such cracking.

Application of Stainless Steels

In view of the great interest now shown by the aircraft designer in non-corroding steels for wings, fuselage, floats and hulls and many detailed parts, the author has dealt at some length with these materials.

Whilst the application of non-corrodible steels to aircraft construction began in a small way, approximately 15 years ago, in early post-war designs, such as the Supermarine Seagull, Southamptons, Short Rangoons and Kents (with austenitic stainless steel bottoms), and the Blackburn Iris, it is only within the last three years that the general substitution of stainless steels for the materials previously used has become really practicable on a general scale.

The first requirement of the aircraft designer is that such structure should not become heavier or less strong, also that the methods of construction and fabrication, which have become standardised, should preferably not require much modification for the new materials.

The demands made on materials for aircraft purposes include for certain parts a combination of corrosion resistance with very enhanced mechanical properties. These considerations impeded the use of stainless steel for such purposes as spars and ribs, for years, as, although high mechanical properties have been adequately provided on sheets and strips made from carbon steels and nickel steels, the stainless steels available had not, until comparatively recently, the combination of strength and ductility to a sufficient degree to enable, for instance, the formation of small corrugations without cracking, as in the case of certain of the standard alloy steels ordinarily used. In many cases where sufficient ductility was obtained, strength was lowered past the figure at which an economical structure could be built.

The stainless steels now available surmount the difficulties previously experienced, and are now being freely incorporated in machines, and as has already been shown, a large range of stainless steels is covered by Air Ministry specifications.

The designer should have a clear conception of their individual application. In Tables V and VI the author has summarised the best known of these steels and given typical examples of their uses. It can be said, however, that a designer with little previous knowledge of these steels, which in itself is a very wide and highly technical study, can with perfect safety incorporate or substitute the austenitic "Staybrite" class of steel with absolute freedom from certain types of service failures which have been associated with the attempted introduction of some so-called non-corrodible materials.

Although stainless materials requiring heat-treatment (the author refers to the 12/14 per cent. chrome class of steels (D.T.D. 23B., D.T.D. 39, D.T.D. 46A., S.61, S.62, etc.), and also the 2 per cent. nickel, 20 per cent chrome type (D.T.D. 146A., D.T.D. 60A. and S.80), are used to some extent, the austenitic class of nickel-chrome steels (D.T.D. 166A., D.T.D. 171A., and D.T.D. 176), which have their enhanced corrosion-resisting properties without special heat-treatment, are coming to the front more and more.

Apart from aircraft for marine use, where stainless steels are practically essential, even land machines are using these austenitic steels as they can be blanked out into fittings, bent cold, and obviate entirely the necessity of subsequent heat-treatment. They have thus definitely established their practical utility from an ease of manufacture viewpoint, and, whilst high duty non-ferrous alloys are satisfactory from the mechanical standpoint, they have been found in certain cases unreliable when subjected to such conditions as, for example, southern and tropical marine atmosphere. Conditions obtaining during the " sirroc " at Malta, for instance, are particularly destructive.

The author specially would bring to your notice the austenitic nickel-chromium steel (D.T.D. 166A.), which you will see from the tables, whilst still retaining a high degree of ductility, can be given substantial mechanical strength by cold rolling. A proof stress of 50 tons per square inch is obtained, and in addition this material can be edge and spot welded, or have bearing washers welded without subsequent heat-treatment, although it should be noted that the strength of the steel in the vicinity of the weld will be reduced to that of this material in the fully softened condition, *i.e.*, D.T.D. 171A., which has a proof stress of 15 tons per square inch at 0.1 per cent. In practice this means that only those portions showing blue or grey temper film are affected as regards this lowering of proof stress. In the high tensile condition (D.T.D. 166A.) this material is slightly magnetic, but in the fully softened condition (D.T.D. 171A.) it will not affect the compass needle.

Both these steels are completely immune from weld decay, which was the troublesome factor some few years back, and this immunity has been obtained by the addition of tungsten and titanium. It is interesting to note that this material has been successfully used for years on flying boats, and notable examples are the three Short Kent class, which have been operating in the Mediterranean for so many years. The hull plating up to the chine line is actually riveted to Duralumin ribs and frames, and although trouble has been experienced in some cases with austenitic plates riveted to Duralumin frames in regard to galvanic action, the fact that the ribs and plates, in the case of these boats, were white enamelled before assembly has effectively eliminated any danger of galvanic action, and these flying boat hulls are as good to-day as when put into service four years ago.

Their cost of maintenance has been negligible.

> " Scipio " went into service in May, 1931, and has flown 260,000 miles without any trouble whatsoever with her " Staybrite " steel bottom.
>
> " Sylvanus " went into service in July, 1931, and has flown 240,000 miles without any trouble whatsoever.
>
> " Satyrus " went into service June, 1931, and has flown 245,000 miles again without any trouble as regards plating, framing or riveting.

The hulls gave no trouble when this Kent class first went into service. The Duralumin portions of the wing-tip floats gave trouble from galvanic action until it was discovered that this could easily be stopped by putting a piece of zinc about six inches square by $\frac{3}{8}$in. thick on the inside of each wing-tip float. This, as is known, is ordinary marine practice where zincs are placed under the stern to avoid the attack of the mild steel hull plating in the neighbourhood of phosphor-

bronze propellers. These zincs are replaced from time to time (about every six months), and not the slightest trouble has been experienced with the hulls.

It is interesting to note that by coupling up a milli-volt meter between the hull and wing-tip float, a reading of 0.8 of a milli-volt was obtained when both were immersed, the sea acting as the electrolyte.

The white enamelling of the ribs and interior of the hull was a great success, but the zincs actually provided the solution to the trouble.

The " Staybrite " steel rivets in these particular hulls, machined from D.T.D. 176 bar in automatics and drilled hollow have been extremely satisfactory.

Stainless steel floats have been successfully constructed, using both plating and ribs and frames to D.T.D. 166A., and, although these floats were only 18ft. long, much greater difficulty was encountered in getting the weights within those of comparable Duralumin floats than would be experienced in a large sized hull. With this in mind, a weight of only 13 per cent. heavier than Duralumin floats may be considered a remarkable achievement. The floats so far made have stood up in an excellent way with practically no maintenance, and they are left unpainted.

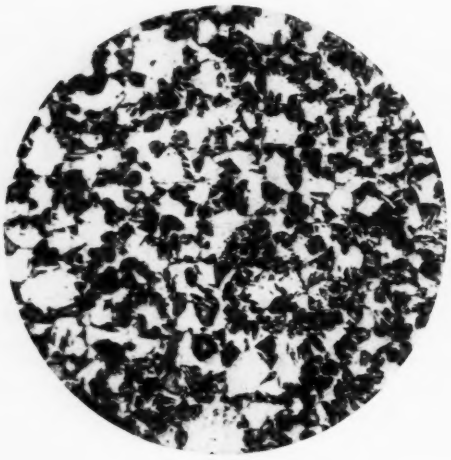
The Metallography of Aero Steels

It is a great advantage to the designer or young aero engineer to be able to picture in his mind the internal structure of the steels or metals which he is employing. The microscope readily discloses the fundamental differences in structure brought about by changes in composition and treatment, and it is of great interest to endeavour to match up the types of structure coincident with the mechanical and physical properties of the different steels. Too much space has already been taken up with other aspects of the subject and, therefore, only very brief comments are now permissible, but a careful study of micrographs presented in Plates 1 to 22 will give an accurate impression of the structures obtained by the treatments at present employed.

In Figs. 1 to 6 representative structures are given for the plain carbon steels. In Fig. 2 is represented the normalised structure of 0.2 per cent. carbon steel, which will be seen to consist mainly of soft ferrite crystals with some small amount of the carbide constituent pearlite interspersed through it. Fig. 1 is interesting as showing that the treatment accorded to the core of a case-hardening steel of much lower carbon, *i.e.*, 0.12 per cent. causes an entirely different layout of the carbide constituent, which is dispersed in a more diluted but effectively hard condition, as confirmed by the mechanical properties in Table III. Figs. 3 and 4 are intended to bring out the great difference resulting in the structure of the same carbon steel when normalised, as shown in Fig. 3 and hardened and tempered as shown in Fig. 4, the massive ferrite constituent occurring in the normalised condition is absent from the hardened and tempered condition. It must, of course, be pointed out that this hardened and tempered structure with a carbon steel could not be obtained in large mass. Figs. 5 and 6 are introduced to show that with the increased carbon content, even in the normalised condition, the soft ferrite constituent disappears. Fig. 7 is introduced to illustrate the difference in structure obtained between a 5 per cent. nickel case-hardening steel core and the comparable core obtained from a carbon case-hardening steel. This micrograph expresses in terms of micro-structure the reason for the much greater crushing strength resulting from the use of nickel. Figs. 8 to 12 are included to give an indication of the structures which are obtained with what the author has described as the structural alloy steels, after the hardening and tempering procedure applied to them. Perhaps the outstanding point here is the extremely fine structure obtained in the chrome-vanadium steel, as used for valve springs. In the instance of these steels the solid solution has been more or less trapped *in situ*, and the tempering operation

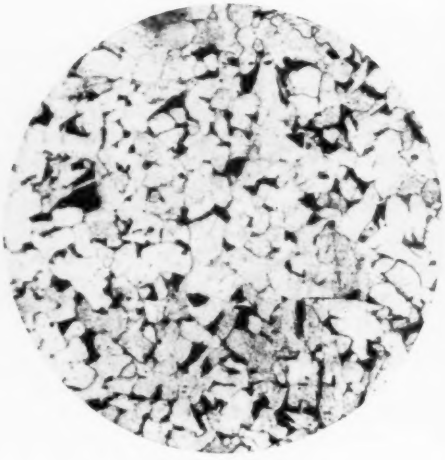
applied has left the decomposition products dispersed throughout the whole of the mass of the material, hence the properties as disclosed in Table III. In Fig. 13 we have portrayed the microstructure of nitrided steel, showing the nitrided case, whilst in Fig. 14 we have at a higher magnification the structure of the body of such material. If the author were asked to describe and explain the constituents present in the nitrided case of this steel, he would have to excuse himself on the ground that as yet the metallography of this nitrided zone, as in the case of many other structures, has not yet been worked out. Suffice it to say that the hard outer layers have a high nitrogen content, and that the structure shown in Fig. 13 accompanies this hard condition. Figs. 15 and 16 are given in illustration of the structures of two typical valve steels.

As regards the metallography of the rustless steels, it will be obvious that a paper in itself might well be given on the subject, but in Figs. 17 to 21 will be found examples of the structures obtained in these steels sufficient to give an accurate idea of the difference in structure obtained with the various types. A comparison between Fig. 21 and Fig. 18 establishes in no unmistakable manner the fundamental differences in constitution and structure of the austenitic and martensitic rustless steels. The 13 per cent. chromium stainless steel responds to hardening and tempering as in the case of the structural alloy steels, whereas the austenitic 18/8 steels of the " Staybrite " class, when quickly cooled from very high temperatures, have their ductility considerably enhanced, *i.e.*, the austenitic phase is largely preserved at normal temperatures. Fig. 19 illustrates the intermediate type of material containing 18 per cent. of chromium with 2 per cent. of nickel, which is the steel generally supplied to the S.80 specification. Fig. 20 is included to bring out the type of structure resulting from the cold working of the austenitic steels. These steels, whilst they cannot be hardened in the normal manner by quenching from a high temperature, yet by cold working effects the crystal structure becomes deformed, with the result that very high mechanical properties are obtainable, as indicated in Table V.



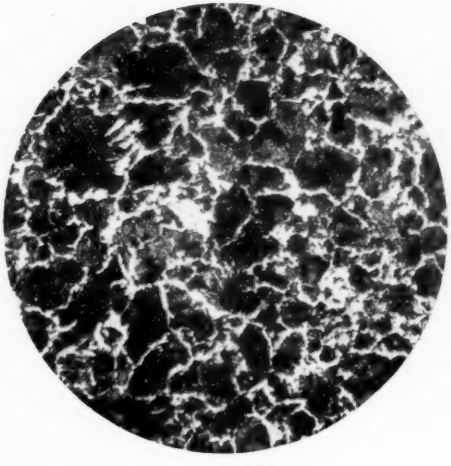
× 200.
.12% Carbon C.H. Steel.
O.Q. 800° *C., W.Q.* 750°*C.*
Steel 1. *Table III.*

FIG. 1.



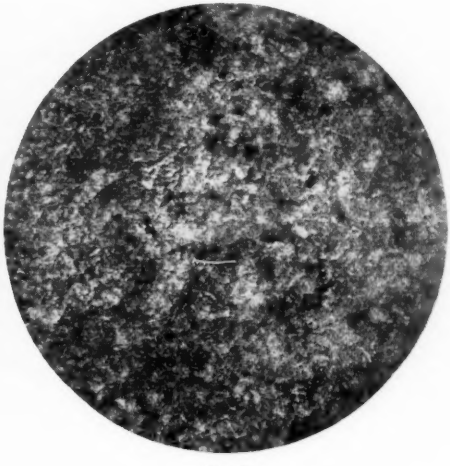
× 200.
.2% Carbon Steel Bar.
Normalised 880°*C.*
Steel 2. *Table III.*

FIG. 2.



× 200.
·4% *Carbon Steel.*
Normalised 850°*C.*
Steel 3. *Table III.*

FIG. 3.

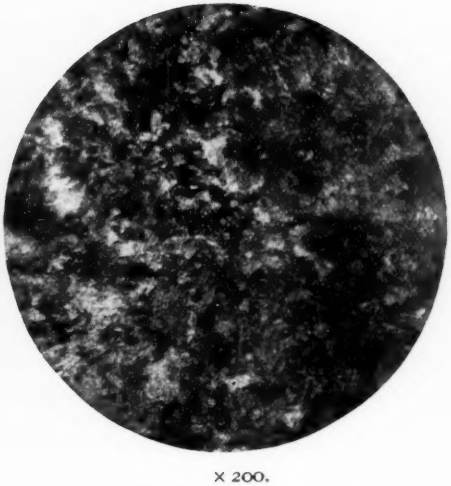


× 200.
·4% *Carbon Steel.*
O.H. 850°*C., T.* 600°*C.*
Steel 3. *Table III.*

FIG. 4.

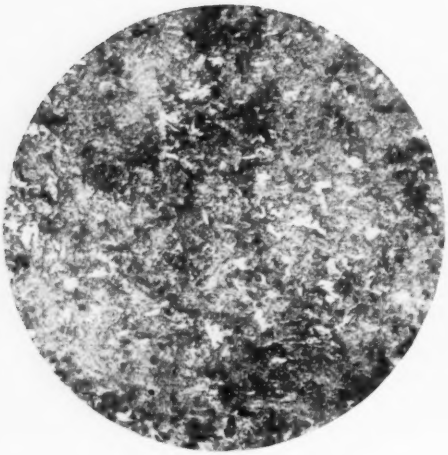
× 200.
·55% *Carbon Steel Cylinders*
(*S.*70-*S.*79). *Normalised* 830°*C.*
Steel 4. *Table III.*

FIG. 5.



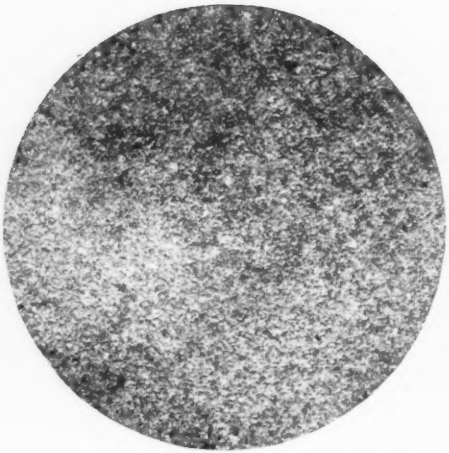
× 200.
·7% *Carbon Key Steel.*
Normalised 810°*C.*

FIG. 6.



× 200.
5% *Nickel C.H. Steel.*
O.Q. 830°*C.*, *W.Q.* 750°*C.*
Steel 8. *Table III.*

FIG. 7.

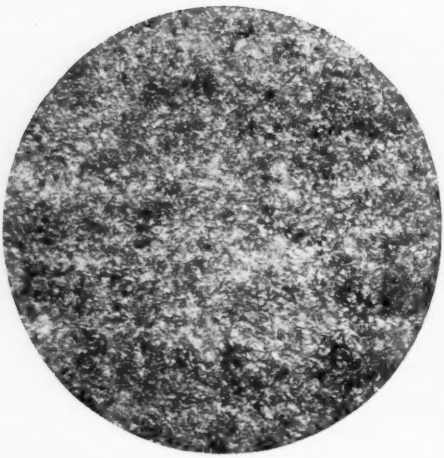


× 200.
3% *Nickel-Chrome Steel.*
O.H. 830°*C.*, *T.* 600°*C.*
Steel 9. *Table III.*

FIG. 8.

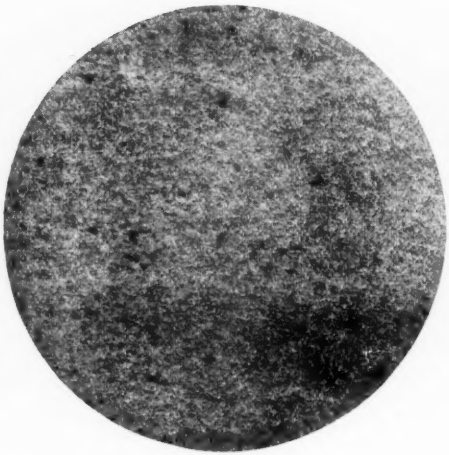
× 200.
Air Hardening Nickel-Chromium Steel.
A.C. 820°*C.*, *T.* 200°*C.*
Steel 11. *Table III.*

FIG. 9.

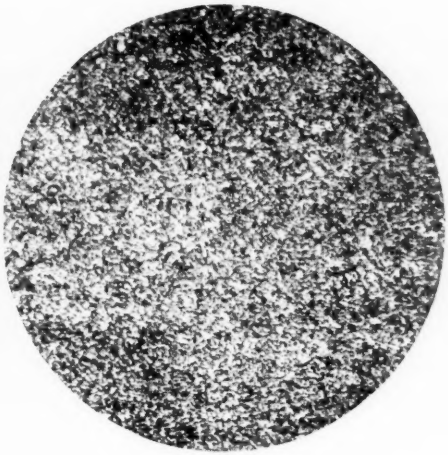


× 200.
Chrome-Molybdenum Steel.
O.H. 850°*C.*, *T.* 630°*C.*
Steel 13. *Table III.*

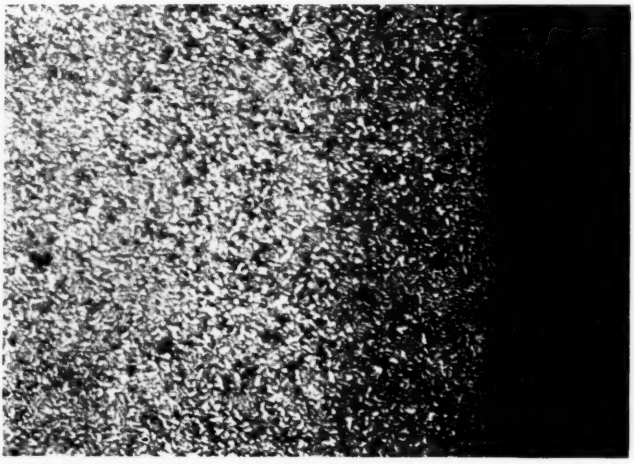
FIG. 10.



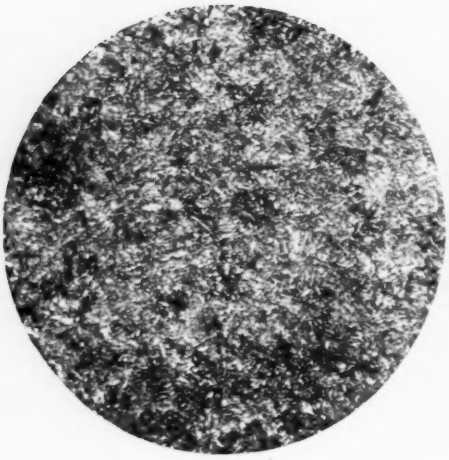
× 200.
Chrome-Vanadium Spring Steel.
O.H. 850°*C.*, *T.* 420°*C.*
Steel 16. *Table III.*
FIG. 11.



× 200.
Silico-Manganese Spring Steel.
O.H. 860°*C.*, *T.* 450°*C.*
Steel 17. *Table III.*
FIG. 12.

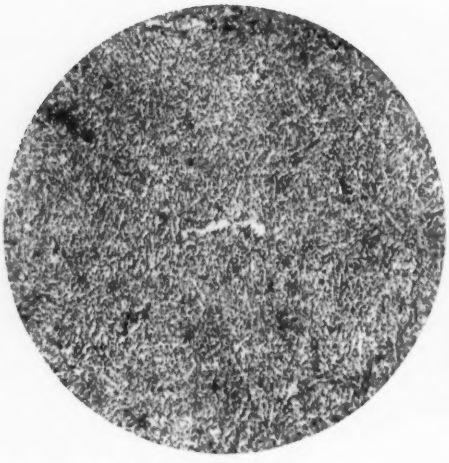


× 100.
Chromium-Aluminium Nitriding Steel.
(Nitrided Case.)
Steel 18. *Table III.*
FIG. 13.



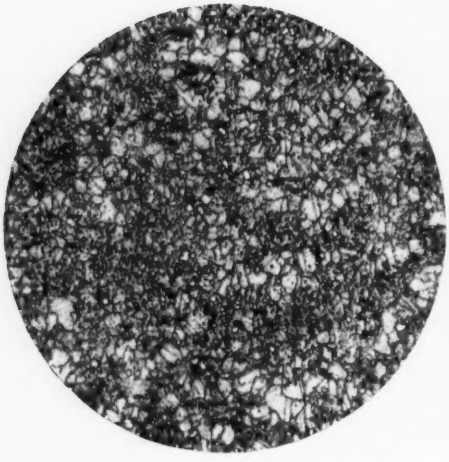
× 200.
Chromium-Aluminium Nitriding Steel.
O.Q. 900° *C., T.* 600°*C.*
Steel 18. *Table III.*

FIG. 14.



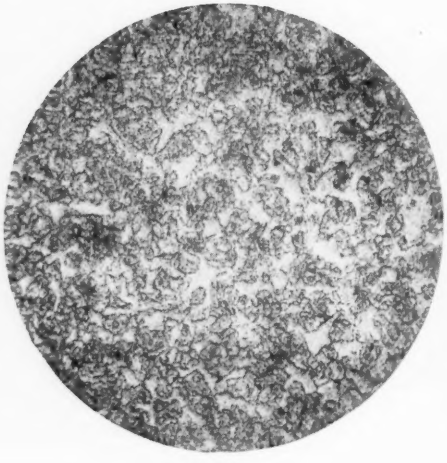
× 200.
Silicon-Chromium Valve Steel.
O.Q. 960°*C., T.* 700°*C.*
Steel 28. *Table V.*

FIG. 15.



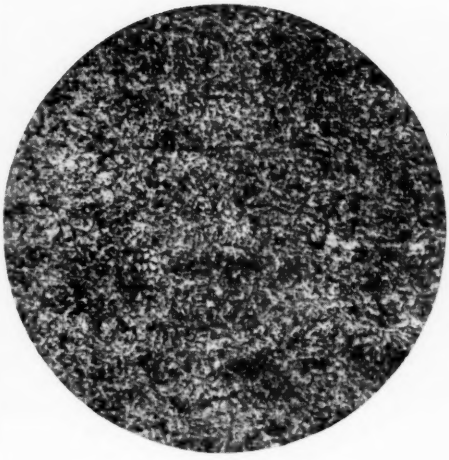
× 200.
Nickel-Chromium-Tungsten Steel
(.30 *Carbon*). *A.C.* 1050°*C.*
Steel 26. *Table V.*

FIG. 16.

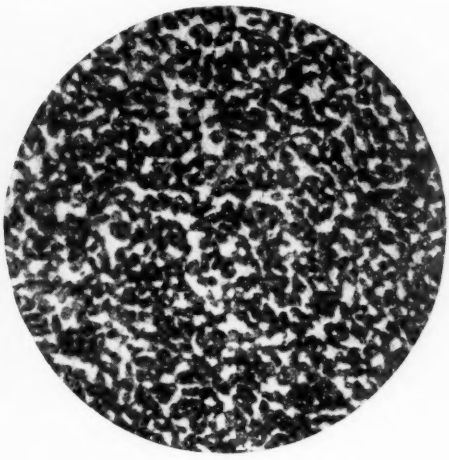


× 200.
Stainless Iron.
A.C. 1000°*C., T.* 700°*C.*
Steel 19. *Table V.*

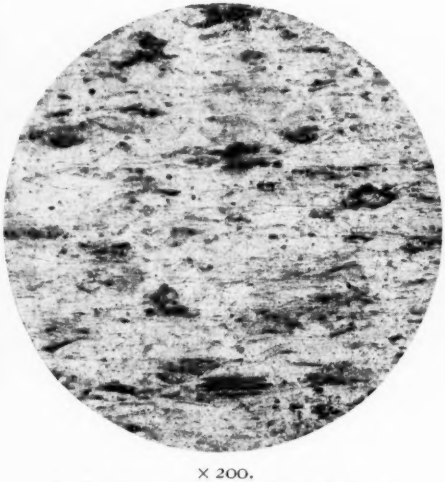
FIG. 17.



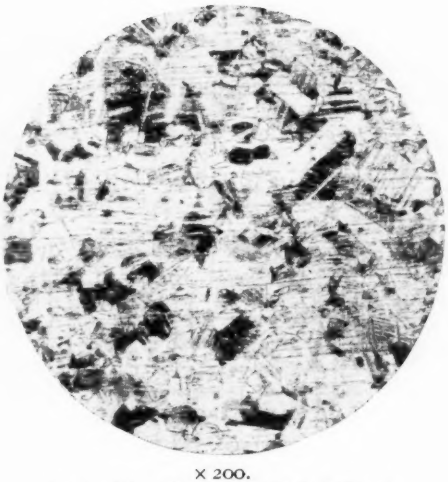
× 200.
Medium Carbon Stainless Steel.
O.Q. 975°C., *T.* 650°C.
Steel 22. *Table V.*
FIG. 18.



× 200.
High Chromium-Low Nickel Steel.
O.Q. 950°C., *T.* 520°C.
Steel 24. *Table V.*
FIG. 19.

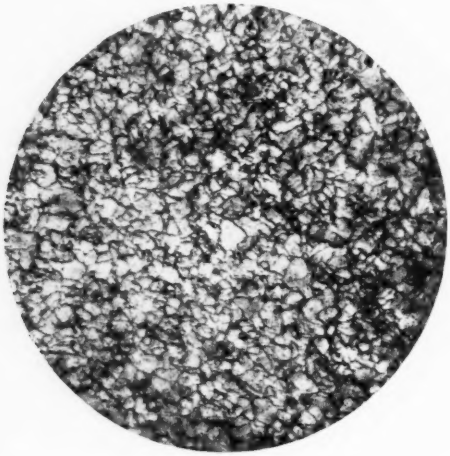


× 200.
Austenitic Chromium-Nickel Steel.
Cold-Rolled.
Steel 25. *Table V.*
FIG. 20.



× 200.
Austenitic Chromium-Nickel Steel.
A.C. 1150°C.
Steel 25. *Table V.*
FIG. 21.

Fig. 22 is of interest as portraying the complex structure resulting from the addition in large quantities of manganese, nickel and chromium, as exemplified in the high expansion steel No. 30, particulars of which are found in Table V.



× 200.

Nickel-Manganese-Chrome Steel.
A.C. 1000°*C.*
Steel 30. *Table V.*

FIG. 22.

To interpret adequately the changes taking place during hardening and tempering in relation to the microstructure, it is essential to have full data relative to the heating and cooling curves, and in Diagram 2 will be found such data from representative steels. The major absorptions of heat on heating and the major evolutions of heat on cooling represent the essential phase changes in the steels, and it will be observed how fundamentally the position of these critical points is modified by the changes in composition.

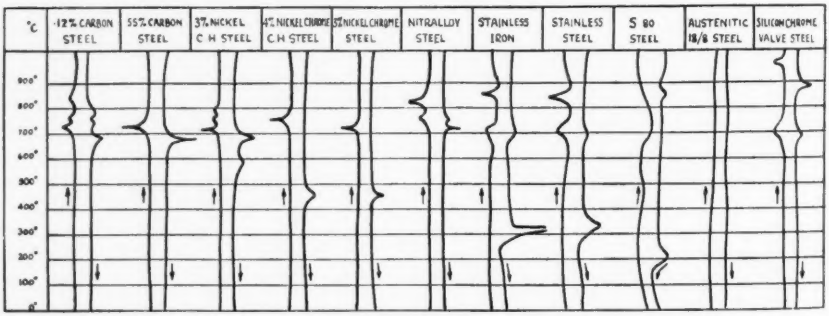


DIAGRAM 2.

Concluding Remarks

The scheme which was in the author's mind when he began to prepare this work has, in practice, really proved too large for the compass of a single paper. There are certain aspects of the matter which he would like to have gone into more fully, had space permitted, but he feels that by collecting together the data relative to aircraft steels, in this manner, it is in a convenient form for discussion and deduction.

The obvious question is, are we at the present time employing too great a variety of steels in aircraft construction? The answer is difficult, since both aero engineering and metallurgy are rapidly progressive sciences, and to ensure that aero engineering has the full advantage of metallurgical progress it must invariably be the case that some steels have proved themselves, whilst others are being initiated. The attitude of the Air Ministry in readily preparing D.T.D. specifications has been most helpful to progress. Having said so much, however, it will undoubtedly be clear that all the steels which are being employed are not necessary and that reduction in the number might be achieved after consideration.

Many points have been raised in the paper, and the author looks forward to an interesting discussion, which he trusts will be helpful.

In conclusion, the author would like to thank Mr. G. Stanfield, Mr. J. G. Hopcraft, and others of his colleagues who have been so helpful in assisting him to correlate such a large mass of data. He also wishes to take this opportunity of thanking the companies with which he is associated for permission to put all the facts on the table, and in this connection his thanks are due to Messrs. Thos. Firth and John Brown, Ltd., as regards the structural steels, and to Messrs. Firth-Vickers Stainless Steels, Ltd., as regards the rust, acid and heat-resisting steels of different types which have been discussed.

TABLE I.

TYPICAL AIRCRAFT PERFORMANCE DATA.

Year.	1905.	1914.	1918.	1934.		
Type of aircraft	Experimental Machine [1]	Service fighter.[2]	Service fighter.[2]	Service fighter.[3]	Heavy Commercial Aircraft.[4]	Light Private Aircraft.[5]
Total weight fully laden (lbs.), per b.h.p.	61	20/25	8	4	11	17
Motor—						
R.p.m. at full load	(1,000)	1,000/1,600	1,500/1,800	2,250	2,100	2,300
Maximum b.h.p. developed ...	12/15	80/100	150/200	525	425	120
Weight (lbs.)	240	300/400	300/400	916	750	285
Weight (lbs.) per unit b.h.p. ...	16	$3\frac{1}{2}$-4	2-$2\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{3}{4}$	$2\frac{1}{3}$
Performance—						
Maximum speed (m.p.h.) ...	(30/40)	60/90	110/130	210	180	130
Time (minutes) to climb 10,000ft.	No available lift.	Normal ceiling about 10,000ft.	10/12	—	10/15	$22\frac{1}{2}$
,, ,, ,, ,, 20,000ft.			30	10	Absolute ceiling 20,000ft.	Absolute ceiling 17,500ft.

[1] The Wright Brothers' successful machine.
[2] Average figures for the most up-to-date aircraft.
[3] Hawker "Fury." Rolls-Royce Supercharged "Kestrel."
[4] Lockhead "Vega," Pratt and Whitney D.G.5 "Wasp."
[5] De Havilland D.H.80 "Puss Moth," Gipsy III.

TABLE II.

STRENGTH WEIGHT RATIOS OF VARIOUS MATERIALS.

Material. (All Wrought Condition except †).	1. Specific Gravity.	2. Modulus Tons/sq. in.	3. 0.1 % Proof Stress Tons/sq. in.	4. Maximum Stress Tons/sq. in.	5. Fatigue Limit.	Ratio 3/1.	Ratio 5/1.
Mild steel (2S.21)	7.87	13,400	15.0	32.0	±14.0	1.92	1.78
Medium carbon steel (2S.1) ...	7.86	13,300	18.0	35.0	±15.0	2.28	1.92
3½% Nickel steel (S.69)	7.87	13,050	45.0	55.0	±27.0	5.73	3.43
Special steel (S.65)	7.86	13,200	56.0	65.0	±30.0	7.14	3.82
Nickel-chromium C.-H. steel (S.82)	7.87	13,100	44.0	85.0	±37.0	5.60	4.71
Nickel-chromium steel (2S.28) ...	7.87	13,150	72.0	100.0	±41.0	9.26	5.22
Stainless steel (D.T.D. 46A.) ...	7.725	13,400	65.0	83.4	±36.0	8.42	4.66
Stainless steel (D.T.D. 168) ...	7.731	13,500	60.0	80.4	±35 appr.	7.75	4.53
Copper sheet (annealed) 2B.4 ...	8.90	8,000	2.6	14.0	± 3.5	.29	.39
Brass sheet (annealed) 2B.12 ...	8.50	8,000	5.0	18.0	± 7.5	.59	.88
Duralumin bar 3L.1	2.85 max.	4,510	15.0	25.0	± 9.5	5.26	3.33
Super Duralumin	2.82	4,510	18.0	30.0	±12.5	6.38	4.43
Y. Alloy bar (heat-treated) 2L.25 ...	2.85 max.	4,825	13.0	22.0	±10.0	4.56	3.51
†Aluminium-copper alloy (12% Cu.) (2L.8)	2.90	4,920	—	9.0	± 3.0	—	1.04
R.R. 56 (forgings), D.T.D. 130 ...	2.75	4,920	22.0	27.0	±11.5	8.0	4.18
Magnesium alloy (Elektron), D.T.D. 88	1.82	2,800	7.0	15.0	± 7.0	3.84	3.84
Ash	.53	630	—	3.57	—	2.25*	—
Spruce	.40	536	—	2.50	—	2.08*	—
Oak	.69	760	—	4.00	—	1.95*	—
Teak	.80	1,070	—	5.40	—	2.26*	—

* Proof Stress assumed ½ Maximum Stress.

TABLE

STRUCTURAL

MATERIAL.	Number.	TYPICAL ANALYSIS.							NUMBERS OF SPECIFICATIONS.
		C.	Si.	Mn.	Ni.	Cr.	Va.	Mo.	
Carbon steels.	(1)	.12	.18	.65	.10	—	—	—	D.T.D. 41, 82. 2 T.26. 2 S.21. (See also D.T.D. 141. 12 A. 2 S.14.)
	(2)	.28	.20	.75	.22	—	—	—	2 S.1. S.71. (See also 2 S.3. D.T.D. 17A.)
	(3)	.41	.14	.50	.12	—	—	—	2 S.6. S.76.
	(4)	.55	.23	.58	.16	—	—	—	S.70. S.79. D.T.D. 153, 5 W.3, 5 W.8. (See also D.T.D. 215. 187.)
1½% manganese steel.	(5)	.29	.19	1.4	.21	—	—	—	D.T.D. 126, 124. T.35. 2 T.1. (See also T.45. D.T.D. 137, T.50. 138.)
3% nickel C.H. steel.	(6)	.12	.15	.50	3.10	—	—	—	3 S.15.
3½% nickel steel.	(7)	.43	.19	.64	3.58	0.2	—	—	S.69.
5% nickel steel.	(8)	.12	.14	.30	4.9	—	—	—	2 S.4. S.67. (See also S.83A.)
3½% nickel chromium steel.	(9)	.31	.14	.70	3.4	.70	—	—	D.T.D. 98A. (99), 100. 3 S.11. 2 S.2.
Nickel-chromium C.H. steel.	(10)	.14	.21	.40	4.49	1.2	—	—	S.82.
Nickel-chromium A.H. steel.	(11)	.28	.15	.50	4.20	1.5	—	—	2 S.28, 54A. 2T2.
Nickel-chromium molybdenum-vanadium steel.	(12)	.23	.18	.55	3.04	1.47	.19	.53	S.65. S.81.
Chrome-molybdenum steel.	(13)	.32	.13	.55	—	1.05	—	.25	D.T.D. 167.
Chrome-molybdenum high tensile steel.	(14)	.30	.21	.59	.89	.88	—	.94	D.T.D. 228.
Carbon-chrome ball-bearing steel.	(15)	.99	.21	.48	.12	1.41	—	—	
Chrome-vanadium steel.	(16)	.46	.17	.57	.15	1.40	.18	—	D.T.D. 4A.
Silicon-manganese steel.	(17)	.52	1.95	1.05	—	.05	—	—	D.T.D. 115.
Chrome-aluminium steel for nitriding.	(18)	.39	.23	.61	—	1.63	Al. 1.10	.18	D.T.D. 87.

III.

STEELS.

TREATMENT.	MECHANICAL PROPERTIES.								
	Proof 0.1% tons/sq. in.	Yield Point tons/sq. in.	Max. Stress tons/sq. in.	Elongation per cent.	R./A. per cent.	Izod.	Brinell.	Fatigue ± tons/ sq. in.	Modulus of Elasticity tons/sq. in
Normalised 900°C.	16.2	17.5	28.5	37	64.5	65	124	13.5	13400
Refined W.Q. 760°C.	14.1	17.2	31.3	33	60.9	85	137	14.0	13400
Normalised 870°C.	18.5	19.5	35.8	31.5	57.0	32	151	14.9	13300
Normalised 850°C.	20.8	23.9	38.9	27	53.0	28	170	16.5	13300
Normalised 830°C.	23.0	27.8	46.5	21	38.0	10	202	19.0	13250
Oil Harden 830°C. Temp. 600°C.	29.5	41.0	56.0	18	55.0	12	241	22.5	13150
Normalised 850°C.	20.5	23.6	40.2	30.0	57.0	50	187	17.5	13300
Oil Harden 850°C. Temp. 640°C.	24.0	29.1	40.5	31.0	59.0	85	187	17.5	13300
Refined W.Q. 760°C.	26.0	35.1	49.3	20.0	49.0	70	217	20.5	13050
Oil Quenched 850°C. Temp. 570°C.	53.0	56.4	63.8	22.0	61.0	55	293	27.0	13050
Refined 840°C. W.Q. 760°C.	25.9	40.1	58.8	18.0	48.0	28	269	26.0	13000
Oil Harden 820°C. Tempered 600°C.	50.0	54.5	60.1	22.0	61.0	68	277	26.5	13100
Refined Oil Q. 760°C.	48.3	73.0	89.0	18.0	63.7	30	418	39.0	13100
Air Harden 820°C. Temp. 250°C.	65.2	85.0	106.0	12.5	45.0	15	495	45.0	13150
Oil Q. 850°C. Temp. 640°C. A.C.	65.1	68.7	73.9	21.5	69.0	48	340	32.0	13200
Oil Harden 820°C. Temp. 680°C.	36.5	45.5	53.8	24.5	67.0	65	255	22.0	13150
Oil Q. 875°C. Temp. 640°C. A.C.	53.7	58.5	64.0	19.0	57.0	50	293	27.0	13150
W.H. 810°C.	—	—	—	—	—	—	650	—	13000
Oil Q. 850°C. Temp. 490°C.	72.0	82.5	87.0	16.0	48.0	24	402	42.0	13000
Oil Harden 860°C. Temp. 480°C.	66.0	78.5	90.2	14.0	32.0	11	418	43.0	12500
Oil Harden 900°C. Temp. 650°C.	47.6	50.2	57.5	22.5	59	50	269	24.9	12800

TABLE

STRUCTURAL

MATERIAL.	Number.	TYPICAL ANALYSIS.						
		C.	Si.	Mn.	Ni.	Cr.	Va.	Mo.
Carbon steels.	(1)	.12	.18	.65	.10	—	—	—
	(2)	.28	.20	.75	.22	—	—	—
	(3)	.41	.14	.50	.12	—	—	—
	(4)	.55	.23	.58	.16	—	—	—
1½% manganese steel.	(5)	.29	.19	1.4	.21	—	—	—
3% nickel C.H. steel.	(6)	.12	.15	.50	3.10	—	—	—
3½% nickel steel.	(7)	.43	.19	.64	3.58	0.2	—	—
5% nickel C.H. steel.	(8)	.12	.14	.30	4.9	—	—	—
3½% nickel-chromium steel.	(9)	.31	.14	.70	3.4	.70	—	—
Nickel-chromium C.H. steel.	(10)	.14	.21	.40	4.49	1.2	—	—
Nickel-chromium A.H. steel.	(11)	.28	.15	.50	4.20	1.5	—	—
Nickel-chromium-molybdenum vanadium steel.	(12)	.23	.18	.55	3.04	1.47	19	.53
Chrome-molybdenum steel.	(13)	.32	.13	.55	—	1.05	—	.25
Chrome-molybdenum high tensile steel.	(14)	.30	.21	.59	.80	.88	—	.94
Carbon-chrome ball-bearing steel.	(15)	.99	.21	.48	.12	1.41	—	—
Chrome-vanadium steel.	(16)	.46	.17	.57	.15	1.40	.18	—
Silicon-manganese steel.	(17)	.52	1.95	1.05	—	.05	—	—
Chrome-aluminium steel for nitriding.	(18)	.39	.23	.61	—	1.63	Al. 1.10	.18

IV.

STEELS.

PHYSICAL PROPERTIES.						
Specific Gravity.	Thermal Expansivity Parts per Million.	Thermal Conductivity.	Electrical Resistivity Mic. per cm.	Weldability.	Air-Hardening Characteristics.	Magnetic Properties.
7.87	13.0	.12	15	Good.	None.	High Permeability.
7.86	12.7	.112	18	F. Good.	None.	Good Permeability.
7.85	12.7	.110	19	Moderate.	None.	Good Permeability.
7.83	12.6	.092	21	Moderate.	None.	Magnetic.
7.86	12.7	.087	21.5	Good.	V. Slight.	Magnetic.
7.88	12.5	.095	21.5	Good.	Present.	Magnetic.
7.87	12.2	.080	26.0	Moderate.	Present.	Magnetic.
7.87	12.4	.075	25.5	Moderate.	Present.	Magnetic.
7.87	12.7	.080	25.0	Moderate.	Present.	Magnetic.
7.87	13.0	.070	23.0	Moderate.	Marked.	Magnetic.
7.87	12.7	.070	27.0	Moderate.	Strong.	Magnetic.
7.86	12.7	.070	24.5	Moderate.	Marked.	Magnetic.
7.84	12.6	.095	22.0	F. Good.	Present.	Magnetic.
7.86	12.5	.070	23.0	Moderate.	Present.	Magnetic.
7.81	12.2	—	—	—	—	Magnetic.
7.83	12.6	.110	23.0	Moderate.	Present.	Magnetic.
7.73	12.5	.045	45.0	Moderate.	Present.	Magnetic.
7.73	(Case 11.8) 13.0	.05	39.0	Moderate.	Present.	Magnetic.

TABLE

RICH ALLOY STEELS

STEEL.	Number.	ANALYSIS. C.	Si.	Mn.	Ni.	Cr.	W.	Ti.	NUMBER OF SPECIFICATIONS.
Stainless iron bar.	(19)	.08	.10	.12	.15	13.5	—	—	D.T.D. 39, 53. 23 B. 97, 161. See also 158.
Stainless iron tubes.	(20)	.10	.21	.32	.18	13.6	—	—	S.61, D.T.D. 102.
		.11	.11	.33	.21	13.7	—	—	D.T.D. 105.
Stainless iron strip.	(21)	.18	.29	.31	.22	13.85	—	—	D.T.D. 46A. 195.
Stainless steel bar.	(22)	.27	.35	.26	.29	13.1	—	—	S.62.
High chromium low nickel steels.	(23)	.11	.13	.15	1.9	17.9	—	—	D.T.D. 146. 185 A. See also 225.
	(24)	.12	.29	.15	2.75	17.7	—	—	D.T.D. 60A. 163, S.80, and 199.
		.12	.30	.23	2.46	18.32	—	—	D.T.D. 168.
Austenitic chromium-nickel stainless steels.	(25)	.11	.52	.29	8.1	18.2	.61	.65	171A. 176A. 207 189
		.12	.55	.30	8.05	17.9	.63	.69	166A. 211 181A.
Chromium-nickel-tungsten valve steels.	(26)	.44	1.1	.71	14.1	14.0	2.05	—	D.T.D. 49A.
		.34	1.39	.46	10.95	21.39	3.16	—	D.T.D. 49A.
	(27)	.42	1.42	.12	20.7	23.5	2.8	—	D.T.D. 49A.
		.41	1.75	.92	28.5	14.4	3.2	—	
Silicon-chromium valve steel.	(28)	.44	3.9	.52	.15	8.1	—	—	
14% tungsten high-speed steel.	(29)	.61	.25	.30	0.1	3.9	14.5	0.7 (V.)	S.68
Nickel-manganese-chromium (high expansion) steel.	(30)	.59	.30	5.1	11.9	3.4	—	—	
12% manganese steel (castings).	(31)	1.1	0.5	11.9	—	—	—	—	D.T.D. 9B.

V.

FOR SPECIAL PURPOSES.

TREATMENT.	MECHANICAL PROPERTIES.								
	0.1% Proof tons/sq. in.	Yield Point tons/sq. in.	Max. Stress tons/sq. in.	Elongation per cent.	R/A. per cent.	Izod. ft. lbs.	Brinell.	Fatigue Range ± tons/sq. in.	Modulus of Elasticity tons/sq. in.
A.C. 950. T.750°C. A.C.	20.0	24.0	33.9	32.0	72	80	163	14.0	13400
O.H. 940. T.700°C. or C. Drawn and T.	24.0	31.0	40.8	20.0	71	90	196	17.5	13400
O.H. 950. T.550°C.	37.0	43.5	55.2	19.0	57	45	262	24.5	13400
A.H. 1000°C. T.150°C.	67.8	76.5	83.4	7.0	—	—	380	43	13400
O.H. 940°C. T.700 W.Q.	34.0	38.5	50.2	25	61.5	50	241	21.0	13700
Sheet Softened 670°C.	31.0	34.0	41.8	19	—	—	202	—	13500
O.H. 960. T.520 W.Q.	39.0	42.7	56.8	19.5	55.8	45	269	23.5	13500
O.H. 950. T.	64.1	71.1	80.4	8.0	—	—	377	—	13500
A.C. 1050°C.	15.3	17.5	42.9	60	62	100	175	17.5	12900
C.R. Sheet and Strip. Tubes. Wire Ropes.	45	50.8	66	18	—	—	—	—	12500
Valves A.C. 950°C.	—	39	54.6	39.5	47.5	38	255	20	13000
Valves A.C. 950°C.	20	38	57	25.2	35	40	269	21	13000
Valves A.C. 950°C.	20	38	54	26.0	34	42	255	20.5	13000
Valves W.Q. 1000°C.	—	36.9	48.5	38	46	49	235	—	13000
O.Q. 950. T.700°C.	45	53.2	66.2	16	32	low	290	24	12500
Annealed.	20.8	28.3	51.6	16.6	27.5	low	241	18	14500
Forged.	20.5	32.5	56.2	38	48	90	295	22	13200
A.C. 1050°C.	15.2	21	42	50	69	110	185	19	13200
W.Q. 1000°C.	—	—	—	—	—	—	210	—	—

TABLE

RICH ALLOY STEELS

STEEL.	Number.	ANALYSIS.						
		C.	Si.	Mn.	Ni.	Cr.	W.	Ti.
Stainless iron bar.	(19)	.08	.10	.12	.15	13.5	—	—
Stainless iron tubes.	(20)	.10	.21	.32	.18	13.6	—	—
		.11	.11	.33	.21	13.7	—	—
Stainless iron strip.	(21)	.18	.29	.31	.22	13.85	—	—
Stainless steel bar.	(22)	.27	.35	.26	.29	13.1	—	—
High chromium-low nickel steels.	(23)	.11	.13	.15	1.9	17.9	—	—
	(24)	.12	.29	.15	2.75	17.7	—	—
		.12	.30	.23	2.46	18.32	—	—
Austenitic chromium-nickel stainless steels.	(25)	.11	.52	.29	8.1	18.2	.65	.61
		.12	.55	.30	8.05	17.9	.69	.63
Chromium-nickel-tungsten valve steels.	(26)	.44	1.1	.71	14.1	14.0	2.05	—
		.34	1.30	.46	10.95	21.39	3.16	—
	(27)	.42	1.42	.12	20.7	23.5	2.8	—
		.41	1.75	.92	28.5	14.4	3.2	—
Silicon-chrome valve steel.	(28)	.44	3.9	.52	.15	8.1	—	—
14% tungsten high-speed steel.	(29)	.61	.25	.30	0.1	3.9	14.5	.7 V.
Nickel-manganese-chrome (high expansion) steel.	(30)	.59	.30	5.1	11.9	3.4	—	—
12% manganese steel (castings).	(31)	1.1	0.5	11.9	—	—	—	—

VI.

FOR SPECIAL PURPOSES.

Specific Gravity.	Thermal Expansion 0–300° C. Parts per Million.	Thermal Conductivity.	Electrical Resistivity.	PHYSICAL PROPERTIES.		
				Welding Characteristic.	Air-Hardening Properties.	Magnetic Properties.
7.725	11.3	.045	55	Moderate.	Very Slight.	High Permeability.
7.725	11.3	.045	55	Moderate.	Very Slight.	High Permeability.
7.725	11.3	.045	55	Moderate.	Very Slight.	High Permeability.
7.725	11.3	.045	57	Moderate.	Not very marked.	Magnetic.
7.738	11.2	.044	60	Less Good.	Notable.	Magnetic.
7.731	11.3	.038	73	Less Good.	Notable.	Magnetic.
7.731	11.3	.038	75	Less Good.	Notable.	Magnetic.
7.731	11.3	.038	75	Less Good.	Notable.	Magnetic.
7.905	17.5	0.33	74	Good.	None.	Non-Magnetic.
7.905	17.5	0.33	74	Good.	None.	Non-Magnetic.
7.92	17.2	.032	80	Moderate.	None.	Non-Magnetic.
7.90	15.9	.027	87	Moderate.	None.	Non-Magnetic.
7.70	16.7	.031	92	Moderate.	None.	Non-Magnetic.
8.0	16.3	.030	92	Moderate.	None.	Non-Magnetic.
7.6	12.9	.03	80.0	Poor.	Marked.	Magnetic.
8.55	11.3	.025	65	Poor.	Marked.	Magnetic.
7.99	22.2	.025	74	Moderate.	None.	Non-Magnetic.
7.88	19.0	.028	70	F. Good.	None.	Non-Magnetic.

APPENDIX

AIRCRAFT STEEL

STEEL.	ANALYSIS.										MECHANICAL				
	C.	Si.	Mn.	S. Max.	P. Max.	Ni.	Cr.	Va.	Mo.	W.	0.1% Proof Stress tons/sq. in.	Yield Point tons/sq. in.	Max. Stress tons/sq. in.	Elongation per cent.	R/A. per cent.
MILD STEELS.	.04/.12	0/.20	.20/.50	.04	.04	—	—	—	—	—	—	—	0/22	—	—
Carbon up to .20% A.	—	—	—	.05	.05	—	—	—	—	—	—	—	20/28	—	—
	0/.18	0/.30	0/1.5	.05	.05	—	—	—	—	—	—	28+ 17+	30+ 24+	—	—
	.10/.18	0/.30	0/.90	.05	.05	—	—	—	—	—	—	—	32+	20+	50+
	0/.10	—	0/.60	.05	.05	—	—	—	—	—	—	—	—	—	—
	0/.20	—	—	.05	.05	—	—	—	—	—	—	-	20	—	—
MILD STEELS. (Carbon up to .20/.35%) B.	.15/.25	0/.30	.50/.90	.06	06	—	—	—	—	—	—	—	35/42	12+	35+
	.20/.30	0/.30	.50/.90	.06	.06	—	—	—	—	—	—	—	35/42	15+	40+
	.25/.35	0/.30	.50/.90	.06	.06	—	—	—	—	—	—	—	35/42	15+	55+
	.30/.45	0/.30	.50/.90	.06	.06	—	—	—	—	—	—	—	—	—	—
	.20/.25	0/.30	0/.60	.05	.05	—	—	—	—	—	—	—	28+	—	—
	.25/.35	0/.30	0/1.20	.05	.05	—	—	—	—	—	—	—	25/35	25+	50+
	.25/.35	0/.30	0/1.20	.05	.05	—	—	—	—	—	—	—	30/40	25+	50+
	.20/.26	.20/.40	.40/.80	.05	.05	—	—	—	—	—	—	—	26+	20+	—
MEDIUM CARBON STEELS. (.35/.45) C.	.35/.45	0/.30	0/1.20	.05	.05	0/1.00*	—	—	—	—	—	—	35/45	20+	40+
	.35/.45	0/.30	0/1.20	.05	.05	0/1.00*	—	—	—	—	—	—	40/50	22+	40+
HIGHER CARBON STEELS. D.	.50/.60	0/.30	.40/.75	.05	.05	—	—	—	—	—	—	—	45+	18+	30+
	.50/.60	0/.30	.40/.75	.05	.05	—	—	—	—	—	—	—	55+	15+	35+
	.35/.60	0/.30	.50/.90	.05	.05	0/1.20*	—	—	—	—	—	—	55/65	10+	—
	.70/.80	0/.30	0/1.00	.04	.04	—	—	—	—	—	—	—	95/120	—	—

* Optional.

I.

SPECIFICATIONS.

PROPERTIES SPECIFIED.				REMARKS.			
Izod ft. lbs.	Brinell.	Close Bend Radius.	Reverse Radius.	Treatment	Spec. Number.	Description.	Applications, etc.
—	—	½T.	—	—	D.T.D.12A.	Sheets.	Water jackets, Exhaust. Manifold.
—	—	oT.	—	C.R. C.A.	D.T.D.141.	Sheets.	Low-stressed Parts.
—	—	—	—	N. 900°C. After Ann.	D.T.D.41.	Tubes.	—
40+	—	—	—	After final treatment.	2 S.14.	Bars, Billets, Forgings.	(Casehardening)
—	—	—	—	—	D.T.D.82A.	Wire.	—
—	—	—	—	—	2 T.26.	Tubes.	Suitable for Welding.
—	—	—	—	Fully softened.	2 S.1.	5/16in. and under Bars.	—
—	—	—	—	Fully softened.	2 S.1.	5/16in. to 1½in. Bars.	—
(Elon +Red of A	gation uction rea)			Fully softened.	2 S.1.	1½in. and over Bars.	—
—	—	—	—	Fully softened.	2 S.1.	Bars.	—
—	—	½T.	2-3 on 3T.	Normalised 860°C. A.C.	2 S.3.	Sheets.	Suitable for Welding.
20+	109/ 163	—	—	Normalised 870°C.	S.71.	Bars, Billets, Forgings, Drop Forgings.	—
25+	131/ 174	—	—	H. 870°C. O.Q. T.600°C. O. or W.Q.	S.77.	Same as S.71.	—
—	—	—	—	Annealed.	D.T.D.17A.	Castings.	—
20[1] +	146/ 201	—	—	Normalised 850°C.	2 S.6	Bars, Billets, Forgings, Drop Forgings.	[1] Up to 2½in. diam. Bars or Flats.
35[2] +	174/ 223	—	—	Harden 850°C. O.Q.	S.76.	Same as 2 S.6.	[2] Not over 4in. diam. or across.
—	197/ 241	—	—	Normalised 830°C.	S.70.	Bars, Billets, Drop Forgings, Cylinders.	—
—	235/ 285	—	—	Harden 830° O.Q. T.550° 650° A.C.	S.79.	Same as above.	—
25+	241/ 293	—	—	—	D.T.D.153.	Bars.	Pins and Bolts.
—	—	—	—	Blueing 200°-375°C.	D.T.D.5A.	Wire.	Valve Springs.

AIRCRAFT STEEL SPECI

STEEL.	ANALYSIS.										MECHANICAL PROPERT					
	C.	Si.	Mn.	S. Max	P. Max.	Ni.	Cr.	Va.	Mo.	W.	0.1% Proof Stress tons/sq. in.	Yield Point tons/sq. in.	Max. Stress tons/sq. in.	Elongation per cent.	R/A. per cent.	Izod (ft. lbs. Brinell
HIGHER CARBON STEELS. D. (continued.)	0/.85	0/.30	0/1.00	.04	.04	—	—	—	—	—	—	—	120/160	—	—	—
	.70/+	0/.30	0/1.00	.05	.05	—	—	—	—	—	—	—	—	—	—	—
	0/3.30	0/2.3	.60 1.20	.11	.30	0/.30*	.20/.70	—	—	—	Valve Guides up to 1in. 1.0 to 1.5in. over 1.5in.		16+ 14+ 13+	—	—	—
	.40/.60	0/.30	.50/.90	.05	0.05	—	—	—	—	—	—	—	55/65	—	—	—
	.40/.60	0/.30	.50/.90	.05	0.05	—	—	—	—	—	—	—	55/65	—	—	—
1½% MANGANESE STEEL E.	0/.30	0/.30	0/1.75	.05	.05	—	—	—	—	—	—	—	40+	20+	—	35
	0/.30	0/.35	0/1.75	.05	0.5	—	—	—	—	—	30+[1] 25+[2]	.2% P.S.	35+[1] 30+[2]	—	—	—
	0/.40	0/.35	0/1.75	.05	.05	—	—	—	—	—	—	—	35+	—	—	—
	0/.30	0/.35	0/1.75	.05	.05	—	—	—	—	—	25+[2] (.2% P.S.)		45+[1] 30+[2]	—	—	—
	0/.50	0/.35	0/1.75	.05	.05	0/3.75*	—	—	—	—	45+ (.2% P.S.)		50+	—	—	—
	0/.30	0/.30	0/1.75	.05	.05	—	—	—	—	—	40+[1]	—	30+[2]	—	—	—
	0/.50	0/.30	0/1.75	.05	.05	—	—	—	—	—	—	—	—	—	—	—
	0/.50	0/.30	0/1.75	.05	.05	—	—	—	—	—	65+	—	—	—	—	—
NICKEL STEELS. (3.0/5.0%) F.	.10/.15	0/.30	.20/.60	.05	.05	2.75/3.50	0/.30	—	—	—	—	—	45/60	18+	45+	40
	.35/.45	0/.30	.50/.80	.05	.05	3.25/3.75	0/.30	—	—	—	—	—	55/65	18+	50+	35

* Optional. [1] Before welding. [2] After welding.

STEEL SPECIFICATIONS (*continued*).

CHANICAL PROPERTIES SPECIFIED.			REMARKS.			
Izod (ft. lbs.)	Close Bend Radius.	Reverse Radius.	Treatment.	Spec. Number.	Description.	Applications, etc.
—	—	—	—	D.T.D.215.	High Tensile Wire.	—
—	90° on 3T	—	Harden and Temper.	D.T.D.187.	Strip.	Magneto Drive Couplings, Cylinders, Pistons.
—	—	—	Combined Carbon .50/.90%	D.T.D.169.	Iron Castings.	Valve Guides.
—	—	—	—	5 W.3.	Streamline Wires.	—
—	—	See also—	High Tensile Flexible Wire and Wire Rods.	5 W.8. S W.6-3 W.1-4 W.2.	Tie Rods (Swaged).	—
35-	—	—	Welded Max. Stress 30+	D.T.D.126.	Bars.	For Welding.
—	—	—	Blueing 350°-480°C.	T.35.	Tubes.	For Welding.
—	—	—	Blueing 350°-480°C.	2T.1.	Tubes.	—
—	—	—	Blueing 350°-480°C.	T.45.	Tubes.	—
—	—	—	Blueing 350°-480°C.	T.50.	Tubes.	—
—	2T	—	—	D.T.D.124.	Strip.	For Welding.
—	½T	—	Close annealed, Cold Rolled Strip H.860° and Temp.	D.T.D.137.	Sheet and Strip.	—
—	3T./5T.	2 on 3T.	Same as above.	D.T.D.138.	Strip.	—
40+	—	—	Refine 860° A.O. or W.C. Normalised 850/880°C.	3 S.15.	Bars, Billets, Forgings, Drop Forgings.	—
35+	—	—	Harden 830° O.Q. Temper 530/630° O. or W.Q. Refine 830°C. A.O.W.	S.69.	Same as above.	—

AIRCRAFT STE SPECI

STEEL.	ANALYSIS.										MECHANI				PROPER	
	C.	Si.	Mn.	S. Max	P. Max.	Ni.	Cr.	Va.	Mo.	W.	0.1% Proof Stress tons/sq. in.	Yield Point tons/sq. in.	Max. Stress tons/sq. in.	Elongation per cent.	R/A	
NICKEL STEELS. 3.0/5.0% F.	.08/ .14	0/ .30	0/ .35	.05	.05	4.60/ 5.20	0/ .10	—	—	—	—	—	40/60	20+	4	-
continued.	0/ .16	0/ .30	0/ .40	.05	.05	4.75/ 5.50	0/ .30	0/ .25*	0/ .50*	0/ 1.00*	—	—	70+	13+	4	-
	0/ .25	0/ .30	0/ .60	.05	.05	4.50/ 5.00	0/ .20	—	—	—	—	—	48+	—	-	-
NICKEL-CHROMIUM STEELS. and Nickel-Chromium with Alloys. G.	0/ .35	0/ .30	0/ .70	.05	.05	3.00/ 5.00	.50/ 1.50	0/ .25*	0/ .65*	0/ 1.00*	42+	—	55+	—	-	-
	.25/ .35	0/ .30	.45/ .70	.05	.05	3.00/ 5.00	.50/ 1.50	0/ .25*	0/ .65*	0/ 1.00*	65+	—	0/45 S	oftened	-	-
	.25/ .35	0/ .30	.45/ .70	.05	.05	3.00/ 5.00	.50/ 1.50	0/ .25*	0/ .65*	0/ 1.00*	40/ 50	—	—	—	-	-
	.25/ .35	0/ .30	.45 .70	.05	.05	3.00/ 5.00	.50/ 1.50	0/ .25*	0/ .65*	0/ 1.00*	55+	—	—	—	-	-
	.22/ .28	0/ .30	.35/ .65	.05	.05	2.75/ 3.50	1.00/ 1.40	0/ .25*	0/ .65*	0/ 1.00*	—	—	65/70	17+	4	29 32
	.28/ .35	0/ .30	.45/ .75	.05	05	3.00/ 3.75	.50/ 1.30	0/ .25*	0/ .50*	0/ 1.00*	—	—	65/75	16+	4	29 34
	.25/ .35	0/ .30	.45/ .70	.05	.05	3.00/ 3.75	.50/ 1.00	0/ .25*	0. .65*	0/ 1.00*	—	—	55/65	18+	5	24 29
	.25/ .32	0/ .30	.35/ .60	.05	.05	3.75/ 4.50	1.00/ 1.50	0/ .25*	0/ .65*	0/ 1.00*	—	—	100+	12+	2	44
	0/ .18	0/ .30	0/ .50	05	.05	4.00/ 4.50	1.00/ 1 60	0/ .25*	0/ .50*	0/ 1.00*	—	—	85+	12+	3	Soft 277
	.25/ .35	0/ .35	.45/ .70	.05	.05	3.00/ 5.0	.50/ 1.50	0/ .25*	0/ .50*	0/ 1.00*	—	—	85/110	8+	-	38 51
	—	—	—	.05	.05	—	—	—	—	—	—	—	55/65	18+	5	24 29
CHROME-MOLYB-DENUM STEELS. H.	.25/ .45	.10/ .30	.40/ .80	.05	.05	—	.80/ 1.20	—	.15/ .30	—	—	40+	45+	—	-	-
	.25/ .35	0/ .35	0/ 1.00	.05	.05	0/ 1.00	.50/ 1.50	0/ .25*	.90/ 1.50	0/ 1.00*	—	—	55/65	18+	-	248 293
CHROME-VANADIUM STEELS. I.	.40/ .50	0/ .30	.50/ .70	.05	05	—	1.00/ 1.50	0/ .25	—	—	—	—	95/110	—	-	-

* Optional.

STEEL SPECIFICATIONS *(continued)*.

MECHANICAL PROPERTIES SPECIFIED.					REMARKS.			
Elongation per cent.	B.A. Hardness.	Brinell.	Close Bend Radius.	Reverse Radius.	Treatment.	Spec. Number.	Description.	Applications, etc.
7+	4[illegible]0+	—	—	—	Harden 740° O.Q. Harden 760° W.Q.	S.67.	Bars, Billets, Forgings, Drop Forgings.	—
8+	4[illegible]5+	—	—	—	Refine 830°C. O. or W.	S.83.	Same as above.	—
—	—	—	1½T/ OT.	2 on 3T.	Harden 840° Temper 450/ 600°C. A.C.	2 S.4.	Sheets.	Not for Welding.
—	—	—	OT.	2 on 3T.	Parts from soft sheets Harden 850° A. or O.C.	D.T.D.98A.	Sheet.	—
ened	—	—	½T/3T 5T.	2 on 3T.	—	D.T.D.54A.	Sheet. 65 tons P.S.	—
—	—	—	½T/3T/ 5T	2 on 3T.	—	D.T.D.100.	40/50 P.S. Strip.	—
—	—	—	3T	—	Harden and Temper.	D.T.D.99.	55-ton P.S. Strip.	—
7+	40[illegible]5+	293/ 321	—	—	Harden 830° O.Q. Temper 500/ 600°C. O. or W.Q.	S.65.	Bars, Billets, Forgings, Drop Forgings.	—
6+	40[illegible]5+	293/ 341	—	—	Same as above.	S.81.	Same as above.	—
8+	5[illegible]8+	241/ 293	—	—	Same as above.	3 S.11.	Same as above.	—
2+	25[illegible]3+	444+	—	—	Harden 820°C. Cool still A. T.250°C. Max.	2 S.28.	Same as above.	—
2+	35[illegible]2+	Softened 277 Max.	—	—	Harden 760° O.Q. Temp. 200° Max. Opt.	S.82.	Same as above.	—
8+	[illegible]	388/ 514	—	—	—	2 T.2.	85-ton Tubes.	Axle Tubes
8+	5[illegible]2+	241/ 293	—	—	—	2 S.2.	Bars for machining. Finished Machine Parts.	—
—	[illegible]	—	—	—	—	D.T.D.167.	45-ton Tubes.	—
18+	[illegible]3+	248/ 293	—	—	Harden 875°C. O.Q. Temper 600°C. Min.	D.T.D.228.	Bars, Billets, Forgings, Bars not exceeding 2½in.	Crankshafts, Airscrews.
—	[illegible]	—	—	—	—	D.T.D. 4A.	Valve Spring Wire.	Valve Spring Wire.

AIRCRAFT STEEL SPECI

STEEL.	ANALYSIS.										MECHANICAL			PRO
	C.	Si.	Mn.	S. Max.	P. Max.	Ni.	Cr.	Va.	Mo.	W.	Al.	0.1% Proof Stress tons/sq. in.	Yield Point tons/sq. in.	Max. Stress tons/sq. in.	R/A. per cent.
SILICO-MANGANESE STEELS. J.	.46/.56	1.60/2.10	.80/1.30	.04	.04	0/.40	0/.10	--	--	—	—	—	—	90/100	—
NITRALLOY CHROME-ALUMINIUM STEELS. K.	.35/.45	0/.45	0/.65	.05	.05	0/.25	1.40 1.80	OPT.	.10/.25*	OPT.	.90/1.30*	—	—	55/70	—
SPECIAL ALLOY VALVE STEELS. L.	.50/.70	—	.30/.60	—	—	0/1.00	6.50/8.50	—	—	—	—	—	—	—	—
	1.10/1.60	0/.75	.20/.60	.05	.05	0/.50	11.0/14.0	—	.50/1.00	—	Co. 3.00/5.00	—	—	52+	—
	.55/.70	—	0/.40	—	—	—	3.50+	0/1.00*	—	14.0+	—	—	—	—	—
MANGANESE CASTINGS. M.	1.00/1.50	0/1.00	11.00+	.06	.10	—	—	—	—	—	—	—	—	—	—
STAINLESS STEELS.	0/.10	0/.50	—	—	—	0/1.00	12+	—	—	—	—	—	—	28/35	—
(Low Carbon 12% Chromium Type). N.	0/.10	0/.50	—	—	—	0/1.00	12+	—	—	—	—	—	—	28/35	—
	0/.15	0/.50	—	—	—	0/1.00	12+	—	—	—	—	—	—	30/40	—
	0/.15	0/.50	—	—	—	0/1.00	12+	—	—	—	—	—	—	35/45	50+
	0/.15	0/.50	—	—	—	0/1.00	12+	—	—	—	—	—	30+	30+	—
	0/.15	0/.50	—	—	—	0/1.00	12+	—	—	—	—	—	40+	50+	—

* Optional.

STEEL SPECIFICATIONS (*continued*).

NICAL	PROPERTIES SPECIFIED.					REMARKS.			
Max. Stress tons/sq. in.	R/A. per cent.	Izod ft. lbs.	Brinell.	Close Bend Radius.	Reverse Radius.	Treatment.	Spec. Number.	Description.	Applications, etc.
90/100	–	–	401/444	–	–	Harden 860°C. O.Q. Temper 450/480°C. A.C.	D.T.D.115.	Bars.	Spring Steel.
55/67	–	35+	241/302	–	–	Harden 900°C. O.Q. Temper 600°C. A.C. Anneal 525-550°C. four hrs. and S.C.	D.T.D.87.	Bars, Billets, Forgings, Drop Forgings.	–
–	–	20+	207/269	–	–	Harden 900/950°C. A. or O.C. Temper 650/750°C. A.C.	D.T.D.7.	Same as above.	Valves.
52–	–	–	228/277	–	–	Harden 900/950°C. A.C. Temper 750°C. A.C.	D.T.D.6A.	Same as above.	Valves.
–	–	–	–	–	–	Softened.	S.68.	Same as above.	–
–	–	–	0/241	–	–	Soften 1000°C. Max. W.Q.	D.T.D.9B.	Manganese Castings.	–
28/35	–	25+	131/170	–	–	Treated suitably.	D.T.D.53.	Low Tensile Bars.	—
28/33	–	–	–	OT/½T	2 on 3T	Treated 600/650°C. A.C.	D.T.D.39A.	Low Tensile Sheets.	Fittings and parts of Laminated Fittings.
30/40	–	–	–	½T.	2 on 3T.	–	D.T.D.23B.	Sheets.	Same as above.
35/45	50+	45+	152/207	–	–	Harden 940°C. O.Q. Temper 600/750°C. O. or W.Q.	S.61.	Bars, Billets, Forgings, Drop Forgings.	–
30+	–	–	–	–	–	–	D.T.D.102.	Tubes.	–
50+	–	–	–	–	–	–	D.T.D.105.	Tubes.	–

AIRCRAFT STEEL SPECI

STEEL.	ANALYSIS.											MECHANICAL PROP			
	C.	Si.	Mn.	S. Max.	P. Max.	Ni.	Cr.	Va.	Mo.	W.	Al.	0.1% Proof Stress tons/sq. in.	Yield Point tons/sq. in.	Max. Stress tons/sq. in.	Elongation in 2" per cent.
STAINLESS STEELS. Low Carbon 12% Chromium Type. N. continued.	0/ .15	0/ .50	0/ 1.00	.05	.05	0/ 1.00	12+	—	—	—	—	—	—	30+	—
	0/ .15	0/ .50	—	—	—	0/ 1.00	12+	—	—	—	—	—	18+	28+	—
	.12/ .20	0/ .50	0/ .70	.05	.05	0/ 1.00	12+	—	—	—	—	55/60	—	45 Max	(in condit
	0/ .08	0/ .50	—	—	—	0/ 1.00	13+	—	—	—	—	35+	—	—	—
	.12/ .20	0/ .50	—	—	—	0/ 1.00	12+	—	—	—	—	65+	—	—	—
	.10/ .20	0/ .50	0/ 1.00	.05	.05	0/ 1.00	12+	—	—	—	—	45+ (.2%P.S.)		50+	—
STAINLESS STEELS. Medium Carbon 12% Chromium. O.	.15/ .35	0/ .50	—	—	—	0/ 1.00	12+	—	—	—	—	—	—	46/52	20+
STAINLESS STEELS. High Chromium, Low Nickel. P.	0/ .20	0/ .60	0/ 1.00	—	—	1.0+	16.0/ 20.0	—	—	—	—	45+	—	40+[1] 55+[2]	—
	0/ .20	0/ .60	0/ 1.00	—	—	1.0+	16.0/ 20.0	—	—	—	—	30+	—	40+	—
	0/ .20	0/ .60	0/ 1.00	.05	0.05	1.00/ 3.00	16.0/ 20.0	—	—	—	—	20+	—	35/45	—
	0/ .20	0/ .50	0/ 1.00	.05	0.05	0/ 3.00	16.0/ 20.0	—	—	—	—	—	—	30/50	—
	0/ .25	0/ .50	0/ 1.00	—	—	1.0+	16.0/ 20.0	—	—	—	—	—	—	55+	—
	0/ .25	0/ .50	0/ 1.00	.05	.05	1.0+	16.0/ 20.0	—	—	—	—	—	—	50+	—
	0/ .25	0/ .50	0/ 1.00	—	—	1.0+	16.0/ 20.0	—	—	—	—	—	—	55+	15+
	0/ .25	0/ .50	0/ 1.00	.05	.05	1.0+	16.0/ 20.0	—	—	—	—	60+	—	45 Max.	(in so condit

* Optional. [1] After welding. [2] Before welding.

STEEL SPECIFICATIONS *(continued)*.

MECHANICAL PROPERTIES SPECIFIED.						REMARKS.			
Elongation per Cent. on 2 in. or tons/sq. in.	Izod ft. lbs.	Brinell.	Close Bend Radius.	Reverse Radius.	Treatment.	Spec. Number.	Description.	Applications, etc.
20+	–	–	–	–	–	Fully Softened.	D.T.D.161.	Rods, Wires, Rivets, Split Pins.	–
18+	–	–	–	–	–	As drawn and blued.	D.T.D.97.	Low Tensile Tubes.	–
Max. (in soft condition).		–	½T/3T.	2 on 3T.	Harden 1000°C. Max. A.C.	D.T.D.195.	Strip.	–
–	–	–	–	3T.	–	As rolled.	D.T.D.158.	Strip.	–
–	–	–	–	½/3T/5T.	2 on 3T.	Harden A.C.1000°C. Max. and T.	D.T.D.46A.	Strip.	–
50+	–	–	–	–	–	Harden 1000°C. Max. O. or A.C.	D.T.D.203.	50-ton Tubes.	–
6/52	20+	45+	35+	207/235	–	–	–	S.62	Bars, Billets, Forgings, Drop Forgings.	–
0+[1] 5+[2]	–	–	–	–	2T/5T.	–	Harden 950°C. A.C.	D.T.D.60A.	Sheet and Strip.	–
0+	–	–	–	2T.	2-1 on 3T/5T.	Fully Softened.	D.T.D.146A.	Sheet and Strip.	–
5/45	–	–	–	–	½T.	2 on 3T.	–	D.T.D.225.	Sheet and Strip.	–
0/50	–	–	–	–	–	–	Fully Softened.	D.T.D.185A.	–	Rods, Wire, Tubes, Rivets, Split Pins.
5+	–	–	–	–	–	–	Suitably Softened.	D.T.D.163.	Streamline Wires.	–
0+	–	–	–	229+	–	–	Harden 1000°C. A.C.	D.T.D.199.	Tubes.	–
5+	15+	–	25+	241+	–	–	Harden 950°C. A.O. or W.	S.80.	Bars, Billets, Forgings, Drop Forgings.	–
Max. (in soft condition).			–	T1.	3T. 1 on 5T.	Harden 950°C. Max. A.C. Temper +or−25° Nominal.	D.T.D.168.	Sheet and Strip.	–

AIRCRAFT STEEL

STEEL.	ANALYSIS.											MECHANICAL		
	C.	Si.	Mn.	S. Max.	P. Max.	Ni.	Cr.	Va.	Mo.	W.	Ti.& Cu.	0.1 % Proof Stress tons/sq. in.	Yield Point tons/sq. in.	Max. Stress tons/sq. in.
STAINLESS STEELS. Austenitic Chrome-Nickel. Q.	0/ .20	.20+	0/ 1.00	.05	.05	6.00+	12.0+	OPT.	OPT.	OPT.	OPT.	—	—	30+
	0/ .20	.50+	0/ 1.00	.05	.05	6.00+	12.0+	,,	,,	,,	,,	15+	—	35+
	0/ .20	.50+	0/ 1.00	.05	.05	6.00+	12.0+	,,	,,	,,	,,	15+	—	52/70
	0/ .20	.50+	0/ 1.00	.05	.05	6.00+	12.0+	,,	,,	,,	,,	15+	—	35+
	0/ .20	.50+	0/ 1.00	.05	.05	6.00+	12.0+	,,	,,	,,	,,	15+	—	35+
	0/ .20	.50+	0/ 1.00	.05	.05	6.00+	12.0+	,,	,,	,,	,,	—	—	50+
	0/ .20	.20+	0/ 1.00	.05	.05	6.00+	12.0+	,,	,,	,,	,,	—	—	—
	0/ .20	.20+	0/ 1.00	.05	.05	6.00+	12.0+	,,	,,	,,	,,	—	—	—
HIGH CHROME-NICKEL WELDING ROD. R.	.25/ .55	2.00/ 3.50	.06/ 1.25	—	—	24.0/ 28 0	15.5/ 19.0	—	—	—	—	—	—	—
STAINLESS STEELS. Austenitic Chrome-Nickel Tungsten Valve Steels. S.	0/ .55	0/ 3.00	0/ 1.50	—	—	9.0+	12.0+	—	—	0/ 6.0	—	—	—	—

EEL ECIFICATIONS (*continued*).

ANICAL	PROPERTIES SPECIFIED.						REMARKS.			
Max. Stress tons/sq. in.	Elongation per cent.	R/A. per cent.	Izod ft. lbs.	Brinell.	Close Bend Radius.	Reverse Radius.	Treatment.	Spec. Number.	Description.	Applications, etc.
30+	-	—	—	—	—	—	Soften 1000°C. +W.A.C.	D.T.D.189.	Rods, Wires, Rivets, Split Pins.	After final softening, not to be heated above 350°C.
35+	-	—	—	—	OT/½T	2 on 3T.	Soften and descale.	D.T.D.171A.	Sheet and Strip.	—
52/70	8SWG. and thicker. 12+	—	—	—	1T/1½T/2T.	2 on 5T/3T.	Cold-rolled or C.R. and annealed.	D.T.D.166A.	Sheet and Strip.	—
35+	30+	50+	—	—	—	—	Fully Softened.	D.T.D.176A.	Bars, Billets, Forgings, Drop Forgings.	—
35+	-	—	—	163+	—	—	Fully Softened.	D.T.D.207.	Tubes.	Pipe Lines.
50+	-	—	—	229+	—	—	Hard-drawn or Hard-drawn and Tempered.	D.T.D.211.	Tubes.	—
—	-	—	—	—	—	—	—	D.T.D.181.	3-cwt. Flexible Wire Rope.	—
—	-	—	—	—	—	—	—	D.T.D.236.	Aerial Wire.	—
—	-	—	—	—	—	—	—	D.T.D.61.	Welding Rod.	—
—	-	—	15+	255	—	—	—	D.T.D.49A.	Valves.	—

Appendix II.

MAIN ENGINE PARTS AND POWER TRANSMISSION.

Name of Part.	Carbon and Low Alloy Steels.	Corrosion-Resisting Steels	Non-Ferrous Metals.
Cylinders	M.C. C.I. S.70. D.T.D.169. 2K11.		Al. Alloys. Mang. Bronze.
Cylinder Head Ring ...	Ni.Cr. 3S11.		
Cylinder Liners	Nitralloy D.T.D.87.		
Pistons	M.C. C.I. Ni.Cr. S.70. D.T.D.169. 3S11.		Al.
Piston Rings	C.I. H.S. C.I.Alloy. D.T.D.233. 4K6. S.68.		
Connecting Rods	Ni.Cr. Ni.Cr.H. 3S11. S.65. S.81.		
Crankshafts	Ni.Cr.H. Ni.Cr.Mo.H. Cr.Mo.H. S.65. D.T.D.228. Nitrided D.T.D.228.		
Main Bearing Caps, Covers and Housings	M.C. Ni.Cr. S.70. 3S11.		
Valves	Med.HighCr. Co.Cr.	High Cr. Aust.H.R. Aust.H.R.	
Sleeve Valves	D.T.D.7. D.T.D.6A.	S62. D.T.D.49A. (Nitrided Stems) Aust.H.R. [Nitriding Type]	
Valve Springs	H.D.C. Cr.Va. Si.Mn. D.T.D.5A. D.T.D.4A. D.T.D.115.		
Valve Spring Covers ...	Ni.Cr. A.H.Ni.Cr. 3S11. 2S28.		
Valve Guides	C.I. D.T.D.169.		Ph.Br. Ni.Al. Brass.
Valve Rockers	C.H.C. Ni.Cr.C.H. Ni. 2S14. S.82. S.69.		
Valve Rocker Buttons ...	C.H.C. Ni.Cr.C.H. 2S14. S.82.		
Valve Rocker Rollers ...	H.C. C.H.C. H.S. C.Cr. 2S14. S.68.		

MAIN ENGINE PARTS AND POWER TRANSMISSION (*continued*).

Name of Part.	Carbon and Low Alloy Steels.	Corrosion-Resisting Steels	Non-Ferrous Metals.
Valve Seats	Stellited. C.I. Ni.Cr. M.S. D.T.D.169. 3S11. M.C. H.S. N.M.C. 2S6. S.68.		Al.Br.
Connecting Rod Bolts	Ni. Ni.Cr. Ni.Cr.H. Ni.Cr.Mo.Va. S.69. 3S11. S.81. S.65. 2S2.		
Tappets	C.H.C. Ni.Cr. Ni.Cr.C.H. 2S14. 3S11. S.82.		
Pinions	C.H.C. Ni. Ni.Cr. 2S14. S.69. 3S11. 2S2. A.H.Ni.Cr. Ni.Cr.Mo.Va. Ni.C.H. 2S28. S.65. 3S15.		
Water Jackets	M.S. D.T.D.12A.	Aust.Cr.Ni. 171A.	
Water Pump Spindle	M.S. Ni. Ni.Cr. 2S14. S.69. 3S11. Nitralloy D.T.D.87.	High Cr.Ni.(Mc.) High Cr. D.T.D.185A. S.62. 176. S80.	
Gudgeon Pins	C.H.C. H.S. Ni.Cr.C.H. 2S14. S68. S82.		
Gudgeon Pin Bush (Floating) ...	M.C. C.I. S70. D.T.D.169.		Ph.Br.
Keys	C.Steel. Ni.Cr. 3S24. 3S11.		
Camshaft and Cams	C.H.C. Ni. Ni.Cr.C.H. C.Cr. 2S14. S69. S82.		
Camshaft Drive Shaft	A.H.Ni.Cr. 5% Ni.C.H. 2S28. S83.		
Cam Driving Gears	A.H.Ni.Cr. 5% Ni.C.H. 2S28. S83.		
Bevel Gear Shaft (for overhead camshaft)	C.Steel. Ni. A.H.Ni.Cr. 2S6. S69. 2S28. S76. Cr.Va. 2S2		

MAIN ENGINE PARTS AND POWER TRANSMISSION (*continued*).

Name of Part.	Carbon and Low Alloy Steels.	Corrosion-Resisting Steels.	Non-Ferrous Metals.
Timing Wheels	C.H.C. 2S14. Ni.C.H. 3S15. Ni.Cr. 3S11.		
Push Rod Heads	C.H.C. 2S14. Ni.C.H. 3S15.		
Sleeve Crank	5%Ni.C.H. S67.		
Sleeve Ball Housings	Ni.C.H. 3S15.		
Retaining Ring Nuts	Ni.Cr. 3S11.		
Crankcase			Al.Mg.Alloy.
Oil Thrower	Ni.Cr. 3S11.		
Propellers		Aust.Cr.Ni. 166A.	Various Light Alloys.
Airscrew Shaft	Ni.Cr. 3S11. Ni.Cr.H. S81.		
Airscrew Bolts	Ni.Cr. 3S11. Ni.Cr.H. S65.	High Cr.Ni.(Mc.) S80.	
Airscrew Hubs and Flanges ...	M.C. S76. Ni.Cr. 3S11. Ni.Cr.H. S81. Ni.Cr.H. S65.		
Airscrew Reduction Gears	C.H.C. 2S14. Cr.Va. 2S2. Ni.C.H. S83. Ni. S69. Ni.Cr. 3S11. A.H.Ni.Cr. 2S28. Ni.Cr.C.H. S82.		
POWER UNIT ACCESSORIES			
Generator Drive Couplings ...	Ni.Cr. 3S11. A.H.Ni.Cr. 2S28.		
Magneto Drive Wheels	A.H.Ni.Cr. 2S28. 5%Ni.C.H. S83.		
Magneto Drive Shaft	M.C. 2S6. Ni.Cr. 3S11.	High Cr. S62.	
Magneto Drive Couplings	H.C. Steel. S70. Ni.Cr. 3S11.		
Distributor Drive Shaft	Ni.Cr. 3S11.	High Cr. S62.	

POWER UNIT ACCESSORIES (*continued*).

Name of Part.	Carbon and Low Alloy Steels.	Corrosion-Resisting Steels.	Non-Ferrous Metals.
Distributor Drive Gear	Ni.Cr. 3S11. 5%Ni.C.H. S.83.		
Distributor Rotor Seating		High Cr S62.	
Gun Gear Cam	C.H.C. 2S14. 5%Ni.C.H. S83.		
Blower Driving Gear	A.H.Ni.Cr. 2S28.		
Fuel Pump Body	M.C. 2S6.		
Fuel Pump Gears	C.H.C. 2S14. M.C. 2S6.		
Supercharger Driving Gears ...	Ni.Cr. 3S11.		
,, Impeller	Ni.Cr. 3S11. Ni. S.69.	Aust.H.R. D.T.D.49A.	
,, Impeller Shaft Nuts...	Ni.Cr. 3S11.		
,, Impeller Drive Pinions	Ni.Cr.C.H. S82.		
,, Gears	A.H.Ni.Cr. 2S28. Ni.Cr.C.H. S82.		
Oil Pump Shaft	M.S. D.T.D.12A. Ni.Cr. 3S11.	High Cr. S62.	
Oil Pump Gears	A.H.Ni.Cr. 2S28.	High Cr. S62.	
Oil Coolers	Mild Steel Tinned 3S20. Cr.V. 2S2.	Cr.Ni. D.T.D.171A.	Copper Alloys.
Oil Filters	M.S. D.T D.12A.	Aust.Cr.Ni. D.T.D.176A.	Copper. Monel.
Oil Relief Valve Body		High Cr. S62.	
Stationary Gears	Ni.Cr.H. S65.		
Hand Starter Gears	A.H.Ni.Cr. 2S28.		

POWER UNIT ACCESSORIES (*continued*).

Name of Part.	Carbon and Low Alloy Steels.	Corrosion-Resisting Steels.	Non-Ferrous Metals.
Various Auxiliary Drive Shafts ...	C.H.C. 2S14. A.H.Ni.Cr. 2S28. Ni.Cr. 3S11. Ni.Cr.H. S65	High Cr. S62.	
Various Auxiliary Drive Gears ...	A.H.Ni.Cr. 2S28. Ni.Cr.C.H. S82. 5%Ni.C.H. S83.		
Exhaust Pipes	M.S. D.T.D.12A.	Aust.Cr.Ni. D.T.D.171A.	Al.Cu.
Inlet Pipes	M.S. Ni.Cr. D.T.D.12A. 3S11.	Aust.Cr.Ni. D.T.D.171A.	Al.Cu.
Inlet and Exhaust Pipe Connections		Aust.Cr.Ni. Aust.H.R. D.T.D.171A. D.T.D.49A.	
Inlet and Exhaust Pipe Manifolds	M.S. D.T.D.12A.	Aust.Cr.Ni. D.T.D.171A.	Al.Cu.
Sparking Plug Body	C.I. M.S. Ni.Cr. M.C. D.T.D.169. D.T.D.12A. 2S2. 2S6	High Chromium. Aust.H.R. S62. D.T.D.49A.	Brass.
Sparking Plug Electrode	Ni. H.S. S69. S68.	High Cr. Aust.H.R. S62. D.T.D.49A.	Pure Ni.
Magnets	6%W. Co.W.		
Carburettor Elbow Union		High Cr. S62.	
Carburettor Needle	C.Steel.	High Cr. S62.	
Carburettor Butterfly			Brass.Al.Alloys.
Carburettor Needle Seat			
Radiator	M.S. Mild Steel Tinned. 2S3. S20.	High Cr. S62.	Brass 2T47.
Radiator (Surface Wing Type) ...	Mild Steel Tinned. 3S20.	Aust.Cr.Ni. High Cr.Low C. D.T.D.171A. D.T.D.39.	Al.Brass.Cu.
Tanks	M.S. 2S3.	Aust.Cr.Ni. D.T.D.171A.	Al.Alloys. Cu.Alloys.
Cowling			Al.Alloys.

FUSELAGE HULL AND FLOATS.

Fuselage Tubular Members ...	M.C. Steel. C.Mn. 2T1. T35. T50. D.T.D.167. T45. Cr.Mo. D.T.D.167.	High Cr. High Cr.Ni.(Mc.) Aust.Cr.Ni. D.T.D.105. D.T.D.199. D.T.D.211, 207 D.T.D.203. D.T.D.97.	Al.Alloy Tube.
Fuselage Tubular Members (welded)	M.S. C.Mn. D.T.D.41. T35. T45.	Aust.Cr.Ni. D.T.D.166A. D.T.D.171A.	

FUSELAGE HULL AND FLOATS (*continued*).

Name of Part.	Carbon and Low Alloy Steels.	Corrosion-Resisting Steels.	Non-Ferrous Metals.
Monocoque Fuselage Plating ...	M.S. C.Mn. 2S3. D.T.D.124A.	Aust.Cr.Ni. D.T.D.166A. 171A.	Light Alloys.
Fuselage Plate Fittings	Ni.Cr. 5%Ni. C.Mn. 3S11. 2S4. D.T.D.124A.	Aust.Cr.Ni. High Cr. High Cr.Ni.(Mc.) D.T.D.171A. D.T.D.23B. D.T.D.146A. D.T.D.166A.	
Fuselage Drawn Sections	M.S. C.Mn. Ni.Cr. D.T.D.138. T35. D.T.D.99. D.T.D.137.	High Cr.Ni.(Mc.) Aust.Cr.Ni. D.T.D.168. D.T.D.166A.	
	Ni.Cr.H. Ni.Cr. C.Mn. D.T.D.98A. D.T.D.100. D.T.D.124. D.T.D.54A.	High Cr.Low C. D.T.D.46A. D.T.D.195.	
Hull and Float Frames and Plating		Aust.Cr.Ni. High Cr.Ni.(Mc.) D.T.D.171A. D.T.D.60A. D.T.D.166A. D.T.D.146A.	Light Alloy. Ni.Cu.Alloy.
Plate Fittings	M.S. 5%Ni. Ni.Cr.H. C.Mn. 2S3. 2S4. D.T.D.98A. D.T.D.124. D.T.D.54A.	Aust.Cr.Ni. High Cr.Ni.(Mc.) D.T.D.171A. D.T.D.225. D.T.D.166A. D.T.D.60A. D.T.D.146A. High Cr.Low C. D.T.D.46A.	Light Alloys.
Machined Fittings	Bright Bars. M.C. Steel. Mn.Mo. S1. 2S21. S70. D.T.D.188. 2S6. S71. S76. S77. S79.	High Cr. High Cr.Ni.(Mc.) S62. S80. High Cr.Low C. S61.	Light Alloys.
	Ni.Cr. Cr.Va. A.H.Ni.Cr. S65. 2S2. 2S28. 3S11.		
	Ni. S69.		
Stowages	M.S. 2T26. 2S3.	Aust.Cr.Ni. D.T.D.171A.	Light Alloys.
Tail Skid	M.C. Steel. T50.		
Tail Skid Shoe	Stellited Mn.Steel. M.S. D.T.D.9B. 2S3.	High Cr.Ni.(Mc.) S80.	
Launching Chassis	M.C. Ni.Cr.H. T50. 2T2.	High Cr.Low C. Aust.Cr.Ni. D.T.D.105. D.T.D.211.	
Axle Tubes	Ni.Cr.H. 2T2.		

FUSELAGE—WINGS AND CONTROL SURFACE (*continuation*).

Name of Part.	Carbon and Low Alloy Steels.	Corrosion-Resisting Steels.	Non-Ferrous Metals.
Spars (Drawn Sections)	M.S. Ni.Cr. D.T.D.138. D.T.D.100. D.T.D.137. D.T.D.99.	High Cr.Low C. High Cr.Low C. D.T.D.46A. D.T.D.195.	
	Ni.Cr.H. C.Mn. D.T.D.98A. D.T.D.124A. D.T.D.54A.	High Cr.Ni.(Mc.) Aust.Cr.Ni. D.T.D.168. D.T.D.166A. D.T.D.60A. D.T.D.171A. D.T.D.146A.	Light Alloys.
Ribs	M.C. Ni.Cr.H. C.Mn. T50. D.T.D.54A. D.T.D.124. 2T1.	High Cr.Low C. Aust.Cr.Ni. D.T.D.46A. D.T.D.166A.	Light Alloys.
Bracing Wires	H.D.C. H.D.C. 3W1. 5W8.		
Plate Fittings	M.S. 5%Ni. 2S3. 2S4.		Light Alloys.
Machined Fittings	Bright Bars. M.C. Steel. Mn.Mo. S1. 2S21. S70. D.T.D.188. S71. 2S6. S76. S77. S79.	High Cr. High Cr.Ni.(Mc.) S62. S80.	Light Alloys.
	Ni.Cr. A.H.Ni.Cr. Ni. S65. 2S28. S69. 3S11. 2S2.		
Streamline Wires	H.D.C. 5W3.	High Cr.Ni.(Mc.) D.T.D.163.	
Fork Ends	Bright Bars. M.C. Ni.Cr. 3S1. 2S6. 2S2.	High Cr. HighCr.Ni.(Mc.) S62. S80.	
Struts (Tubular and Streamline and Tubular Spars)	M.C. T1. T50.	High Cr.Low C. High Cr.Ni.(Mc.) D.T.D.105. D.T.D.199.	Light Alloys.
		High Cr.Low C. Aust.Cr.Ni. D.T.D.203. D.T.D.211.	
Metal Wing Covering		D.T.D.97. Aust.Cr.Ni. D.T.D.171A.	Light Alloys.
Hollow Rivets	M.C. T1.	High Cr.Low C. Aust.Cr.Ni. D.T.D.97. D.T.D.207.	Light Alloy.
Solid Rivets	M.S. 2S21.	High Cr.Ni.(Mc.) High Cr.Low C. Aust.Cr.Ni. D.T.D.185A. D.T.D.161. D.T.D.189A. D.T.D.176A	Light Alloys.
Pins for Fork Ends	Ni.Cr. 2S2.	High Cr.Ni.(Mc.) S80.	

CONTROLS.

Name of Part.	Carbon and Low Alloy Steels.	Corrosion-Resisting Steels.	Non-Ferrous Metals.
Control Column	M.S. Ni.Cr. D.T.D.138. D.T.D.100.	High Cr.Low C. High Cr.Low C. D.T.D.46A. D.T.D.195.	
	Ni.Cr.H. C.Mn. D.T.D.98A. D.T.D.124A.	High Cr.Ni.(Mc.) Aust.Cr.Ni. D.T.D.168. D.T.D.166A.	
Rudder Bar	M.S. Ni.Cr. D.T.D.138. D.T.D.100.	High Cr.Low C. High Cr.Low C. D.T.D.46A. D.T.D.195.	
	Ni.Cr.H. C.Mn. D.T.D.98A. D.T.D.124A.	High Cr.Ni.(Mc.) Aust.Cr.Ni. D.T.D.168. D.T.D.166A.	
Pedals	M.S. Ni.Cr. D.T.D.138. D.T.D.100.	High Cr.Low C. High Cr.Low C. D.T.D.46A. D.T.D.195.	
	Ni.Cr.H. C.Mn. D.T.D.98A. D.T.D.124A.	High Cr.Ni.(Mc.) Aust.Cr.Ni. D.T.D.168. D.T.D.166A.	
Control Rods	M.S. Ni.Cr. D.T.D.138. D.T.D.100.	High Cr.Low C. High Cr.Low C. D.T.D.46A. D.T.D.195.	
	Ni.Cr.H. C.Mn. D.T.D.98A. D.T.D.124A.	High Cr.Ni.(Mc.) Aust.Cr.Ni. D.T.D.168. D.T.D.166A.	
Control Cables	M.S. Ni.Cr. D.T.D.138. D.T.D.100.	High Cr.Low C. High Cr.Low C. D.T.D.46A. D.T.D.195.	
	Ni.Cr.H. C.Mn. D.T.D.98A. D.T.D.124A.	High Cr.Ni.(Mc.) Aust.Cr.Ni. D.T.D.168. D.T.D.166A.	
Control Cable Fittings	M.S. Ni.Cr. D.T.D.138. D.T.D.100.	High Cr.Low C. High Cr.Low C. D.T.D.46A. D.T.D.195.	
	Ni.Cr.H. C.Mn. D.T.D.98A. D.T.D.124A.	High Cr.Ni.(Mc.) Aust.Cr.Ni. D.T.D.168. D.T.D.166A.	

CONTROLS.

Name of Part.	Carbon and Low Alloy Steels.	Corrosion-Resisting Steels.	Non-Ferrous Metals.
Tie Rods	H.D.C. **5W8.**	High Cr.Ni.(Mc.) D.T.D.**163.**	
Flexible Wire Rope	C.D.C. **4W2.**	Aust.Cr.Ni. D.T.D.**181A.**	
Levers	M.S. 5%Ni. Ni.Cr.H. **2S3.** **2S4.** D.T.D.**98A.** D.T.D.**54A.**	Aust.Cr.Ni. High Cr.Ni.(Mc.) D.T.D.**225.** D.T.D.**60A.** D.T.D.**166A.** D.T.D.**171A.** High Cr.Low C. D.T.D.**46A.**	Light Alloys.
Pulleys	C.H.C. **2S14.**	High Cr. High Cr.Ni.(Mc.) **S62.** **S80.**	Light Alloys.
Sprockets	Bright Bars. Cr.Va. C.C.H. **3S1.** **2S2.** **2S14.**	High Cr. High Cr.Ni.(Mc.) **S62.** **S80.**	Light Alloys.
Support Fittings	M.S. C.Mn. **2T26.** D.T.D.**124.** **T1.** **2S3.**	Aust.Cr.Ni. D.T.D.**166A.** D.T.D.**171A.**	Light Alloys.
Control Column		Aust.Cr.Ni. D.T.D.**176A.** D.T.D.**211.**	Light Alloy. Ph.Br.
Ball Races	C.Cr.	High Cr. **S62.**	
Chains	C.C.H. Ni.Cr. **2S14.** **S65.**		
Wheel Brake Drum	C.Cr.		Light Alloys.
Tachometer Drive Gear	A.H.Ni.Cr. **2S28.**		

STANDARD PARTS.

Bolts and Nuts (High Tensile) ...	High C.S. Mn.Mo. Ni.Cr. D.T.D.**153.** D.T.D.**188.** **S65.** **3S11.** **2S2.**	High Cr.Ni.(Mc.) High Cr. **S80.** **S62.**	
Bolts and Nuts (Low Tensile) ...	M.S. M.C. **3S1.** **2S6.**	High Cr.Low C. Aust.Cr.Ni. **S61.** D.T.D.**176A.**	
Washers	M.S. H.C. **2S21.** **S70.**	High Cr.Ni.(Mc.) Aust.Cr.Ni. D.T.D.**146A.** D.T.D.**171A.**	Light Alloys.
Split Pins	C. Steel. **2S21.**	High Cr.Low C. High Cr.Ni.(Mc.) Aust.Cr.Ni. D.T.D.**161.** D.T.D.**185A.** D.T.D.**189A**	
Taper Pins	Bright Bars. Cr.Va. 5%Ni. **3S1.** **2S2.** **2S4.**	High Cr. High Cr.Ni.(Mc.) Aust.Cr.Ni. **S62.** **S80.** D.T.D.**176A.**	
Cocks	5%Ni.C.H. **S83.**	High Cr. High Cr.Low C. **S62.** **S61.**	Light Alloys. Cu.Alloys.
Turnbuckles	M.C. Ni.Cr. **S.P.6.** **S.P.6.**	High Cr. High Cr.Ni.(Mc.) **S62.** **S80.**	

References to Appendix II.

Reference Letters.	Description.
C.H.C.	Case Hardening Carbon Steel.
M.S.	Mild Carbon Steel.
M.C.	Medium Carbon Steel.
H.C.	High Carbon Steel.
H.D.C.	Hard Drawn Carbon. High Tensile Steel.
C.Mn.	Carbon Steel with Higher Manganese.
Mn.Mo.	Carbon Steel with Higher Manganese plus Molybdenum.
Ni.C.H.	Nickel Case Hardening Steel.
5% Ni.C.H.	5 per cent. Nickel Case Hardening Steel.
Ni.	3-3½ per cent. Nickel Steel.
Ni.Cr.	3 per cent. Nickel Chromium Steel.
25% Ni.	25 per cent. Nickel Steel.
Ni.Cr.C.H.	Nickel Chromium Case-Hardening Steel.
A.H.Ni.Cr.	Air Hardening Nickel Chromium Steel.
Ni.Cr.H.	Nickel Chromium Higher Tensile Steel—including Nickel, Chromium, Molybdenum Steels.
C.Cr.	High Carbon Low Chromium Steel.
Cr.V.	Chromium Vanadium Steel.
Cr.Mo.	Chromium Molybdenum Steel.
Cr.Mo.H.	Chromium Molybdenum Higher Tensile with Low Nickel.
Si.Mn.	Silico Manganese Spring Steel.
Nitralloy	Special Alloy Steel for Nitriding Process of Surface Hardening.
Med.High Cr.	Medium High Chromium Steel.
Si.Cr.	Silicon Chromium Valve Steel.
H.S.	Tungsten High Speed Steel.
Aust.H.R.	Austenitic Heat-Resisting Steel.
Co.Cr.	Cobalt Chromium Valve Steel.
6%W.	6 per cent. Tungsten Magnet Steel.
Co.W.	Cobalt Tungsten Steel.
N.M.C.	Austenitic Nickel Manganese Chromium Steel.
High Cr.	High Chromium Steel.
High Cr.Low C.	High Chromium Low Carbon Steel.
High Cr.Ni.(Mc.)	High Chromium Low Nickel Type, Stainless Steel (Martensitic).
Aust.Cr.Ni.	Austenitic High Chromium Nickel Steel.
Steel C.	Steel Castings.
C.I.	Cast Iron.
C.I. Alloy	Cast Iron Alloy.

Discussion

Dr. H. J. Gough, F.R.S.: The paper itself covered such a wide scope that one could not attempt to discuss it as a whole. He (Dr. Gough) would confine his remarks to a few aspects raised in which he was particularly interested.

He agreed unreservedly with the author's view regarding the urgent need for restriction in the number of steels used in any one branch of engineering. Speaking as one who was engaged for some years as a designer, he found the great variety of materials offered by the steel makers a source of some embarrassment. Frankly, much of that difficulty was due to the competing commercial interests of those makers who purposely complicated the problem by the use of pet names for their products. He hoped that one result of the amalgamation of steel interests would be the compilation of much smaller but still adequate lists.

In his paper the author referred to the lack of any relation between " proof stress " and " fatigue limit." Dr. Gough entirely agreed and pointed out, in

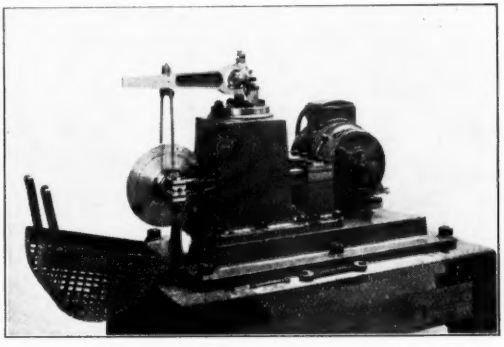


Fig. 1.

addition, that there was no reason, practical or theoretical, why any relation should exist. It was a fallacy to look for such a relation even where cycles of reversed stress were concerned, and the search became absurd when one considered the general case of cycles of stress of which the mean stress was not zero. In discussing design requirements Dr. Hatfield mentioned two conditions, maximum stress and range of stress, and their relation to proof stress value. But there also occurred the case in practice—not necessarily aeronautical practice —where provided failure, either static or fatigue, did not occur, a certain amount of permanent deformation was permissible. For such cases a purely artificial value like the proof stress was not even helpful. What was required was an accurate load extension diagram to fracture; in this connection a Dalby autographic record was invaluable, and Dr. Gough found it surprising that the taking of such records was not more generally employed as a routine test.

Dr. Hatfield referred to two important practical aspects of fatigue on which designers—particularly engine designers—required much more data. The first was the need for more information regarding the variation of safe range of stress with mean stress of the cycle. Such data could only be obtained from laboratories, such as the N.P.L., R.A.E., etc., equipped with suitable machines. These laboratories were not likely to carry out this work on their own initiative, as such investigation was more of technical, rather than scientific, interest. But if the industry or the Society wished to have the information and could supply the necessary funds Dr. Gough had no doubt that arrangements could be made for the tests to be carried out. The second point related to the criteria governing

the resistance of metals to complex fatigue stresses. At the present time he was carrying out an extensive investigation into this subject. As a commencement, the case of combined bending and torsional stress was being studied, as one of direct interest to the crankshaft problem. Dr. Gough then exhibited a few slides. Fig. 1 showed the high-speed machine which had been specially designed. A series of tests on a wide range of aircraft and automobile steels was in active progress. Fig. 2 showed the first result obtained. It would be observed that the constant shear energy criterion was closely obeyed by this material, 0.1 per cent. carbon steel. Subsequent tests, however, on other steels showed that this

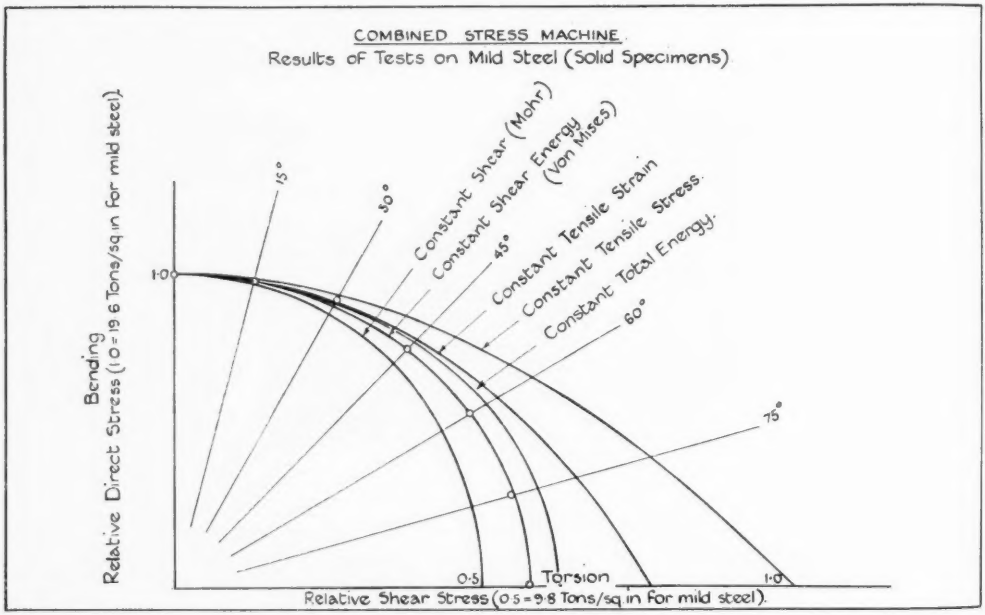


FIG. 2.

was not a universal law, although he believed that a very simple relation, easy to use for design purposes, would probably be found to hold generally. A paper on the subject was in course of publication. He might mention that, through the interest of the author, Messrs. Firth-Brown were preparing specially and presenting the very wide range of steels used in that research.

Dr. Hatfield had referred to many interesting aspects of corrosion. Fig. 3 showed the corrosion-fatigue curves for a group of aircraft materials and it would be seen that in no case did there appear any evidence of the existence of a corrosion-fatigue limit.

Dealing with a point that was not mentioned by the author, Dr. Gough believed that a useful field awaited the production of chains made of stainless steel, if welding difficulties could be overcome. He knew that a start had been made in this direction, but mostly with light chains for ornamental and similar purposes, whereas he now referred to chains for lifting purposes. The cost must, he supposed, exceed that of wrought iron or ordinary steel chains but, even so, there were a number of purposes for which the increased cost would not be a

prohibitive factor. As one example of the demand he might mention chain moorings for aircraft.

Mr. A. H. R. FEDDEN (Fellow): He recalled the fact that he was present at the well-attended meeting in 1917 when Dr. Hatfield read a most instructive paper. He was going to be rash enough to deplore the optimistic tone of the opening remarks of Dr. Hatfield's second paper, although it contained so much matter of interest. There was much progress yet to be made in the use of ferro-alloys for aircraft engines. When one contemplated the material at their dis-

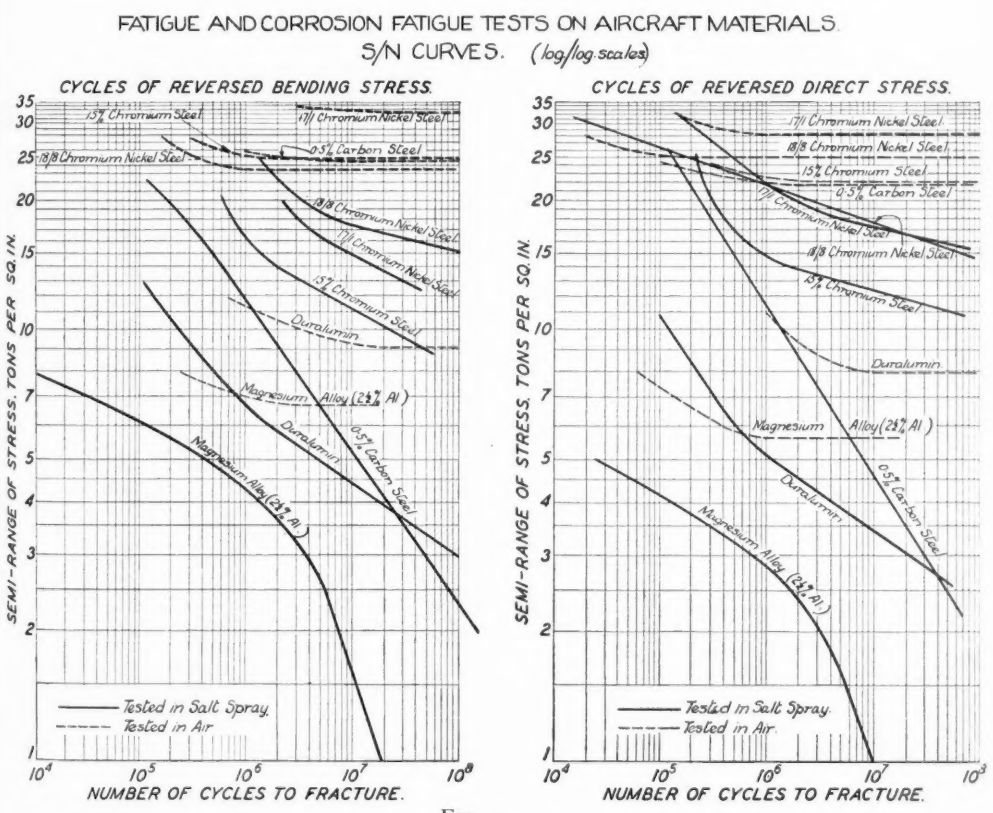

FATIGUE AND CORROSION FATIGUE TESTS ON AIRCRAFT MATERIALS.
S/N CURVES. (log/log scales)
CYCLES OF REVERSED BENDING STRESS.
CYCLES OF REVERSED DIRECT STRESS.
SEMI-RANGE OF STRESS, TONS PER SQ. IN.
NUMBER OF CYCLES TO FRACTURE.
15% Chromium Steel
17/11 Chromium Nickel Steel
18/8 Chromium Nickel Steel
0.5% Carbon Steel
Duralumin
Magnesium Alloy (2½% Al)
Tested in Salt Spray.
Tested in Air.

FIG. 3.

posal for aero engine manufacture, the position was very little better than that of the aero engines themselves. He would like to touch upon three points. Firstly, Dr. Hatfield said that much had been done to improve the cleanliness of steel and to bring about the elimination of inclusions. That might be so, but in Mr. Fedden's opinion a great deal more remained to be done. In this country there were one or two steel stampers who went to almost infinite pains to supply the best possible stampings, but he contended that the right place to eliminate the defects was in the ingot itself. He pleaded very strongly for a much greater improvement in the cleanliness of steel. He entirely agreed with Dr. Hatfield's remarks on the number of specifications. With regard to aero engine manufacture, apart from valves, valve springs and valve seats, Mr. Fedden would welcome

one brand of steel only for the design, and if that steel was the subject of sufficient specialisation and was clean enough, he believed that most excellent results could be obtained therefrom. He was very keen on the use of hardened steel throughout aero engine construction if they were to proceed along the lines which he thought they would have to follow in regard to design. The fatigue range had improved. He fully realised Dr. Hatfield's fear of hardened steel, but he felt that if there was the right degree of collaboration between the steel maker, the engine designer and the machine shop superintendent—and it was necessary that all three should work together—hardened steel could be used to very great advantage. While he did not feel sufficiently competent to criticise many points in Dr. Hatfield's paper he would like to put two questions. He would like to know Dr. Hatfield's views on ingot quartering. Remembering that with quartered ingots less work was put into the material to make the forging, that the central pipe was entirely eliminated, that with actual forged ingots more work was possible but central unsoundness might be retained, was the technique of casting ingots now so good that central unsoundness might be entirely eliminated? There was a reference to etching. The Bristol Company used the magnetic test for cracks due to forging, heat treatment and grinding, with considerable success. Mention was made of valve steels. In his opinion further investigation was required into the question of the production of heat resisting valve steels to combat the corrosion by fuels. In this connection he suggested that more work should be carried out on steels containing an appreciable amount of aluminium. The paragraph dealing with the internal stress and corrosion of stainless steels was extremely interesting from the point of view of exhaust manufacture. In conclusion, Mr. Fedden reiterated his plea for yet cleaner steels for aero engine construction.

Major J. S. Buchanan (Fellow): Although he was not a metallurgist he had read the paper with considerable interest. It was quite true that the aeroplane industry owed a very great deal to Sheffield for the quality of the steels which that city turned out. The tables in the paper had been very instructive to him and rather surprising. The number of specifications and the multitude of purposes to which the material was put were quite a revelation, but he was not sure that Dr. Hatfield's remedy was a good one. It seemed to him that the cause of this multitude of specifications lay in the fact that the engineer and the metallurgist were almost too close together. The metallurgist was always willing to help the engineer out of a difficulty by designing and supplying a new kind of steel to meet his immediate urgent need. That he thought was the origin of many of the specifications for steel that existed at the moment. As was well known, the policy of the department was to keep experimental materials under the list of D.T.D. specifications. As soon as those materials had passed the experimental stage they proceeded to the British Standards Institution, where they became British Standard Specifications. There was, and always would be, a need for a large field of experimental specifications on the line of the existing D.T.D. specifications, no matter what they were called. Their need was important if the experimental science of aviation was to progress.

Major Buchanan had only one real point of criticism of the paper—he was afraid he could scarcely share the author's optimism as regarded stainless steels. In his experience they had to be used with great care as they were rather a quarrelsome family. They quarrelled seriously with the light alloys, and in many cases they quarrelled among themselves. It had been found necessary in some cases to put together in one aeroplane only stainless steels of the same family; if they were of different families they gave rise to a considerable amount of corrosion in the presence of salt water.

Mr. H. Sutton (Fellow): He had great respect for Dr. Hatfield's work and his paper was a substantial contribution to their knowledge of aircraft materials. The lecturer had referred to the fact that parts of structures were

subjected to fatigue stresses to a greater extent than was commonly realised. In Mr. Sutton's experience that was true of aircraft stresses. Sometimes vibration existed in parts of aircraft in which the designer had not suspected that it would arise. Frequently the steady stress was much greater than the fluctuating, but it had to be remembered that the safe range of varying stress was much reduced by the steady stress operating simultaneously, so that small ranges of fluctuating stress while the pieces were under steady stress became of considerable importance.

There were many matters of interest. One special feature of nitriding steels, which had been brought out by Dr. Hatfield on other occasions, was the way in which the hardness of nitriding steels was sustained at elevated temperatures, much higher than with ordinary case-hardened steels. The lecturer's remarks concerning high expansion steel were of special interest, but Mr. Sutton exhorted him to try and give them a high expansion steel which was more easily machinable. It was one of the items in regard to which there was considerable scope for advance. The same remark held good in the case of a number of so-called " corrosion resisting " steels. In the development of some of the newer steels too little attention had been paid to the important point of machinability as a commercial property.

In his paper Dr. Hatfield referred rather glibly to a certain type of corrosion resisting steel as completely resistant as long as its surfaces were kept reasonably free from deposits. Mr. Sutton uttered a caution that under certain conditions of use considerable corrosion might be experienced, even of the so-called corrosion resisting steel. One had seen serious corrosion of such steel at joints with timber. Much could be done by applying temporary preservative to holes through which bolts had to pass, and particularly in marine aircraft. As the result of laboratory tests of the corrodibility of " corrosion resisting " steel, Mr. Sutton had found that the surface condition of the material had a very marked effect and he was glad to find that Dr. Hatfield drew attention to the necessity of descaling, but he gave no information as to how to remove the scales which formed during heat treatment. Mr. Sutton thought that on the whole experience had gone to show that, after heat treatment, forgings, *e.g.*, in S.80, had been found more satisfactorily resistant when free from scales, but uniformly scaled specimens subsequently painted had behaved fairly well.

Referring to the contact corrosion tests Dr. Hatfield had said that Duralumin had been found not to be seriously attacked. In Mr. Sutton's opinion the tests were too short in duration. Duralumin behaved quite well for the first day or two when put in contact with sea water. Even a month was but a short time for testing; if the tests were extended he felt that Dr. Hatfield would not be disappointed in his endeavours to produce some corrosion. The evidence showed that Duralumin must be adequately protected if it was to be brought in close contact with corrosion resisting steel and marine conditions of atmosphere.

The problem of corrosion stress cracking was very interesting. It was very surprising what a small amount of corrosion was needed in some hard steels to cause fracture under a steady stress. All the so-called " corrosion resisting " steels appeared to suffer to some extent, more especially in the higher conditions of tensile strength and hardness. Austenitic steels were much preferable from that point of view. Cases had come to his knowledge of stress corrosion cracking in those steels. In the present state of limited knowledge it was a little difficult to discriminate between the other types and the austenitic in that respect, having found them to be unsatisfactory when used in a relatively very hard condition. In conclusion, Mr. Sutton cautioned the members that some so-called austenitic steels might under certain circumstances be slightly magnetic, even when they were apparently in a softened condition.

Mr. M. LANGLEY (Member): If Dr. Hatfield was right in the statement that very little variation or improvement could be hoped for in the modulus of elas-

ticity in steels, then high tensile steels of 70, 80, 90, even 100 tons were useless to the aircraft engineer, because of their excessive elasticity. Probably that was the reason why the light alloys had achieved such success, in spite of the other manifold advantages of steel. Could Dr. Hatfield answer two questions? The first question related to the temperature effect on the strength of steel. It was known that the strength of any kind of steel varied with the temperature and that the figures for strength which were normally used in aircraft construction were those obtaining at normal atmospheric temperatures only. It was possible that in the future they might be designing aeroplanes for use at high altitudes and high latitudes where temperatures were very much below those which were experienced at the present time. Was the strength of the steels used likely to be adversely affected? Would they be extremely brittle at, say, 40,000 feet above sea level over the poles? The figure might possibly be something of the order of minus 50 degrees Centigrade. The second related to the magnetic properties of the austenitic steels. Dr. Hatfield had shown a curve from which it appeared that there was no critical change point in the austenitic steels down to zero Centigrade. Was there a change point lower than that, and where did that change point occur? Where did the austenitic steels become magnetic? Under the extreme conditions that the speaker had mentioned, if austenitic steel became magnetic, then surely they must watch for its effect on the compass.

Mr. W. O. Manning (Fellow): He inquired what was the future of Dr. Hatfield's particular science—metallurgy. The speaker was not a metallurgist. Looking at the diagrams and the excellent photographs that had been shown on the screen that night, he noticed that all the materials used for structural purposes were aggregated and he was perfectly certain that the strength of an aggregate material must either be that of its weakest constituent or of the adhesion between the constituents. So it would seem, if that were correct, that the ideal structural material would consist of a single homogeneous chemical substance which might possibly be represented by a single crystal. It was, of course, impossible to assume that one could construct an aeroplane part with a single crystal, but it might be possible to estimate the effect of such a thing if it could be done. He would like to know whether it had been possible, from the construction of the shapes and arrangement of crystals and the arrangement of the atoms in a molecule, to get any connection between that and the properties of the material. He thought it was quite obvious that the forces that held one to the other were really those forces that resisted the tensile test on a piece of material. Were he to ask Dr. Hatfield the effect on an alloy nobody had yet tried to make, Dr. Hatfield would probably reply that he could say nothing at all about it, but he (Mr. Manning) would suggest that further investigation into these fundamental matters might indicate some method by which the properties of new alloys might possibly be predicted. He would be interested to hear from Dr. Hatfield whether any work was being undertaken in that direction and whether there had been any success.

Mr. H. J. Pollard (Associate Fellow, Bristol Company): In his paper the lecturer stated that were it not for the ductility requirement necessary for safe deformation during fabrication, as well as considerations of resistance to shock loads, there would be every inducement to aim directly for the highest possible tensile strength, resulting in a raising of tensile strengths to the highest limit with consequent reduction in weights.

In many cases, increasing strengths beyond a certain amount might not result in great weight savings. He could best illustrate one aspect of the case by referring to a stainless steel aircraft built by the Bristol Aeroplane Company, similar in all respects with the standard aircraft except for the steel parts. A " stressing figure " was required for the spars and since it was desired to proceed with the drawings before the receipt of the strip, a figure of 50 tons per square inch was assumed, instead of 65 tons per square inch used for the ordinary spars.

The total increase in spar weight for *all* the spars on that two-seater biplane was only 5lbs., that being the weight of the extra lamination required in the flanges at the places of maximum stress. It could not be said, therefore, in that particular case that lowering the stressing figure by 15 tons per square inch involved a serious increase of spar weight. Actually when the material arrived and a test was made the stress developed was more than that obtained with the ordinary Ni-Cr steel. (In passing he would like to say that it was largely due to the assistance given by Dr. Hatfield and his colleagues that that aircraft was successfully completed to almost the last detail in stainless steel, including such items as stranded cable.)

The case of the monoplane wing was different, a more uniform state of high stress in the spars was possible in the scantlings than in the case of biplane wing spars, and a drop of 15 tons per square inch would certainly entail a much greater increase in weight than 5lbs. for an aircraft of about 4,500lbs. weight. But even in such monoplane structures questions of " instability " of sections becomes a difficulty at high stresses, thus 65 tons/in.^{2} maximum yield strength should be considered good enough.

With regard to fittings, he considered 40 tons per sq. in. 0.1 per cent. proof stress was adequate for 90 per cent. of such parts, and nothing worth while was to be gained by raising that figure. He had in mind wiring plates and the like which easily gave trouble under fluctuating bending stresses if ductility was lacking. For all such parts ductility and high Izod figure were the first requirements, and high tensile strength must take second place.

It was unfortunate as regards the steel strip trade for aircraft structures, that aircraft design was at the moment in a state of transition. Higher speeds and loadings were forcing the use of " rigid coverings " in place of fabric and it was easy to show theoretically that steel was not the best material for such coverings. Theoretical considerations were, however, not the only issues, there was the practical side of the question. Those who visited at the Paris Aero Show in November saw the Italian constructed Savoia Marchetti which was built entirely from 18/8 stainless steel, the covering was seven thousandths of an inch thick, lengths of this were secured together and to the internal framework by shot welding. In spite of the very small thickness the appearance of the aircraft was excellent, and no doubt the machine had adequate strength. He had specially mentioned the material thickness since such covering would be at least as light as that of minimum practicable thickness in aluminium alloy.

It seemed to him, therefore, that it was up to the steel makers to collaborate with the electric welding appliance manufacturers in producing the necessary machinery for this work. Without such collaboration he thought that aircraft manufacturers would follow what was at the moment the easier path and carry on with the use of riveted light alloy sheets for the production of these monocoque bodies. Riveted thin stainless steel was out of the question; quite twice as much internal framework or sheet stiffening was required in the case of thin steel as with the nearly three times thicker light alloy, which meant at least twice as much riveting costs.

Electric welding could easily influence this matter in favour of the steel makers; the stresses in such stiffened sheet combinations were usually low, so trouble from fatigue at welds might be of no account; the method was worth developing since in time of emergency material supplies might render it necessary to use welded thin steel for this work.

He did not, however, wish to give the impression that steel was likely to fall into disuse in aircraft structures; the flanges of monoplane wing spars could easily be proportioned to carry high stresses, thus steel was the material for such components, and at all places of high localised stress, steel could and would be used to advantage.

In connection with the use of steel for spar flanges, it was interesting to read the statement in Dr. Hatfield's paper that Duralumin and stainless steel could be used in contact satisfactorily. But did he mean that when Duralumin was in contact with mild steel the latter corroded, while if the steel were stainless no corrosion due to galvanic action took place? He would also like to ask Dr. Hatfield if ordinary Ni-Cr steel (D.T.D. 54A) had been subjected to similar tests in contact with Duralumin, and if so, what were the results in comparison with stainless steel (" Saitie ") and Duralumin in contact?

Finally, he was in entire agreement with all that the lecturer had said on internal stresses and corrosion stress cracking. With regard to high tensile strip it was very desirable to do all slitting to width before the final heat treatment was carried out; if that was not practicable then the slit edges should be draw-filed. With regard to the reaming of all the small rivet holes required for assembly purposes it was, of course, out of the question, but he had never heard of trouble arising from the non-reaming of the $\frac{3}{32}$in. dia. holes usually employed for line riveting; he could verify Dr. Hatfield's statement that the residual stresses from welding operations were indeed more serious. In conclusion he would like to ask Dr. Hatfield's opinion in regard to the relative merits of D.T.D. 168 and D.T.D. 54A strips in the matter of stress cracking at unreamered rivet holes. Would he expect D.T.D. 168 to behave as well as D.T.D. 54 had done in this respect over a period of years under ordinary conditions on a landplane?

Mr. J. R. Handforth (Napiers): Dr. Hatfield had developed a type of paper of his own which was always interesting and which always contained a vast amount of technical data, much of which had been obtained from costly research under his own direction. He reflected on the various metallurgical changes of importance that had taken place during the past ten years. One of the most important was the development of heat resisting steels of the aero engine valve steel type. This development had modified the whole outlook on internal combustion engines, for whilst poppet valves had once been regarded as the weak point of such engines they were, with modern construction, now well up to all requirements and capable of allowing much further progress with such engines. Contemporary with that development was the introduction into practical engineering construction of steels with controlled coefficients of expansion, such as the N.C.M. valve seats.

A notable change had been the growth of the use of the nickel chrome case-hardening steels to replace the S.14 and five per cent. nickel steels. Another important landmark was the introduction of the nitriding process with its special steels containing chromium and aluminium. Again, there had been the introduction of the sintered carbide cutting tools, and contemporary with that the development of high speed steels containing high percentages of cobalt. Neither of these changes should be omitted in the consideration of Dr. Hatfield's paper, because such developments had been necessary to make it possible to machine some of the new steels which Dr. Hatfield had discussed. Another point of interest was the attempt which had been made by the steel trade to introduce the use of high manganese steels to replace nickel steels for constructional work. There had also been a great improvement in steel castings, particularly those with high alloy content. One point Dr. Hatfield had omitted was the great progress which had taken place in the cast iron industry. Mr. Handforth thought that steel metallurgists were rather prone to forget that cast iron could now be produced with a tensile strength of 45 tons per square inch. New varieties of cast iron were now under test in aero engines for piston rings and scraper rings. There were now austenitic cast irons, and nitriding cast irons, some of the corrosion resisting cast irons having corrosion resisting qualities comparable with those of the high chromium steels.

Finally, there was the tremendously wide improvement of the stainless steels. Apparently there was no limit to development in that direction. Just as they had heard that steel tape was now used for phonographic recording so they would not be very much surprised if Dr. Hatfield told them one day that he had made stainless strip transparent to take the place of celluloid strip in the film industry. (Laughter.)

Concluding, Mr. Handforth said much was heard nowadays of the growing use in the steel industry of high frequency melting plant. Would Dr. Hatfield tell them in what way this development was likely to increase the cleanliness and qualities of the type of steel required in aero engines? One had also heard of a new heat resisting material consisting of an ordinary steel with the addition of approximately 15 per cent. of aluminium. Would Dr. Hatfield tell them what he thought of the possibilities of such material?

Mr. L. W. JOHNSON (Associate Fellow) (*communicated*): He congratulated Dr. Hatfield on the useful tables which he had compiled covering the physical and chemical properties of the whole range of structural steels.

He also commented on the great modesty with which he (Dr. Hatfield) had refrained from referring to the extremely valuable work he himself has carried out in recent years in connection with the metallurgy of steel and with the development of corrosion resisting steels in particular.

Reverting to the large number of steels at present in use in the aircraft industry, he thought that some means should be adopted to reduce that number.

For example, there might be cases in a given structure where, solely from the design aspect, two steels having differing proof stresses are required. Even supposing that the weaker steel is somewhat cheaper it is probable that when the extra cost involved in inspection, storage, care to prevent mixing, etc., is taken into account, it would pay to utilise the stronger steel for both sets of components. In many cases the cost may not be any more, as the same type of steel is used for more than one proof stress range.

The use of many different types of steels involves a great deal of expense in a highly organised system of inspection and control which must be employed to prevent that bugbear of all manufacturers, " mixing of different batches," which can easily occur when the material has some simple shape such as a bar, sheet, etc. This rather suggests that if a manufacturer still desires to use his material in different tensile strengths (and this is often unavoidable as ductility and toughness also play an important part) he should endeavour to obtain that material in a " normalised " or " softened for machining " condition and not heat treat it to the final varying tensile strengths until the components have taken such a shape that they can be definitely recognised the one from the other, *i.e.*, until the danger of mixing has passed.

An objection which can be made to this procedure is that heat treatment will have to be carried out at the manufacturers' works. In view, however, of the excellent automatically controlled heat treatment equipment which is now available, no qualms need be felt on this score, especially since the heat treatment of small components can very often be carried out with greater accuracy and with greater convenience than in, say, long bars.

The above is merely an expression of personal opinion and has been put forward with a view to making some constructive suggestions.

In connection with the table in which the strength-weight ratios of various materials are given, he considered it to be fairer to compare the aluminium alloys by taking the minimum 0.1 per cent. proof stress figures from available specifications.

Thus for " Duralumin " the British Standards Specification 3L1 gives a value of 15 and the specification D.T.D. 130 gives for R.R. 56 alloy a minimum value of 22. In the case of the latter alloy the specific gravity is shown as 2.85, whereas the value is usually below 2.80.

In the section dealing with valve steels the important group which is covered by specification D.T.D. 49A is omitted.

For crankshafts steel, S. 81 is not suggested. He would like to have the author's opinion as to whether or not it is somewhat easier to obtain more consistent test figures with this steel than, say, S. 65.

Steel S. 62 is suggested for oil pump gears. There has been a tendency to use steel to the specification S. 80, owing to its better machining properties. This will also apply to fuel pump gears.

He did not think that steel to the 2 S. 14 specification was to be recommended for airscrew reduction gears owing to the low core strength of the material and, in those instances where a case-hardening steel is called for, he would suggest the use of either S. 82 or S. 83.

Professor J. H. ANDREW, D.Sc. (University of Sheffield) (*communicated*): He was extremely interested in the paper by Dr. W. H. Hatfield. Publications of this character were of great use, not only to the users of steels, and the makers, but also to those interested in the more scientific aspects, and this paper gave in such an accessible form an account of the composition and properties of the many alloy steels used in the aeronautical industry.

He (Professor Andrew) could not help feeling, and he thought Dr. Hatfield would agree with him on this point, that the number of steels used for aircraft work could reasonably be reduced, and that slight variations in treatment of fewer steels would give all the properties which are now provided by such an extensive number.

He also remarked that it would be interesting to know the size of the treated sections used in making the various tests, for, as Dr. Hatfield knows, the particular composition of an alloy steel is largely governed by the mass of metal involved. It is to be regretted that nowadays certain alloy steels, particularly those with the heat resisting properties, contained so many elements. Complex compositions of this character place these steels entirely outside the realms of true scientific investigation, and one cannot say what is the individual effect produced by any one element.

The effect of elements on steel is largely a matter of the manner in which they modify the change points in pure iron, and also the carbide change. For instance, some elements, as is well known, tend to retain the alpha form at all temperatures, and at the same time lower the temperature of the carbide change point, whilst other elements tend to retain the gamma state. It is obvious when all these elements are alloyed together with iron, that an extremely complicated state of affairs will result, and that the evolution of these steels must be regarded as a matter of guess work, or at the best, experimental work carried out in an empirical manner.

Another feature about which further knowledge is desired is with respect to the relation between the added elements and the particular properties produced by them. Can it be said, for instance, why some elements when added to steel give a high elastic limit, or in other cases increase the ductility?

Briefly, it may be said that such a paper as given by Dr. Hatfield, whilst of extreme value to all concerned with steels, emphasises to a very marked degree the paucity of our scientific knowledge with respect to the alloying elements.

REPLY TO DISCUSSION

He assured those present that he always enjoyed replying to discussions, but he was afraid that in the time at his disposal it was utterly impossible to deal with the vast number of interesting points that had been raised. They would have seen that he was very enthusiastic on rustless steel and in this connection he would tell them a story. On the occasion of the Faraday Centenary he was one of six people representing the world of chemistry who were invited by the B.B.C. to broadcast from Savoy Hill and he took as his

subject " The Corrosion of Steel." He was invited to submit his manuscript and, in this, the Censor discovered a paragraph in which, using artistic licence, he had said that owing to the researches on the influence of chromium and chromium nickel in producing rustless steel it would now be possible to produce a rustless battle fleet, that so diverse were the properties of rustless steel that the whole of a ship could be built of it, and he (Dr. Hatfield) had remarked how glorious it would be to see a bright battle squadron sailing the seven seas flaunting the Union Jack. The Censor requested him to call the next time he was in town, and on doing so he was asked to eliminate the paragraph in question, on the ground that it was " propaganda in favour of armaments." He was in exactly the opposite position that night. The statement that they could now make rustless steel of such diverse character as to permit of the construction of a rustless aeroplane was surely not propaganda for armaments, because in civil aviation, which was so important, they were catering for aircraft that would last for many years. In time of war aeroplanes were constructed that might be shot down within the course of a few hours and at such a time it was conceivable that ordinary steels, which were not resistant to corrosion, might be employed, but when it came to civil aviation he was sure they would be inevitably driven to use the rustless steels which he had described. He was sorry he could not oblige Mr. Langley by providing a steel of greatly differing modulus of elasticity, but he did not doubt the ingenuity of the aero engineer to make a great success of the *tout ensemble* characteristics which could be provided.

He was delighted to see Dr. Gough that night; on the metallurgical side they worked together in the greatest friendship and Dr. Hatfield and the firm that he represented were pleased to do everything they could to assist him. Dr. Gough had suggested that the full exploration of the fatigue properties and the complex stress characteristics of ferrous materials was beyond the capacity of such institutions as the N.P.L. and the R.A.E. at Farnborough, thus throwing the ball back to the manufacturers. Surely, he should rather make a plea for greater resources to be placed at the disposal of these institutions. It could hardly be regarded as the function of an industrial concern, which was normally run for profit, to spend too large a proportion of its income on basic information of that kind. That was the view which he (Dr. Hatfield) took and he hoped it would encourage Dr. Gough to increase his own efforts. When Dr. Gough spoke of the straight-line curve pointing to destruction both in the stainless steels and the magnesium alloys, he would ask him one question. What length of time elapsed before destruction occurred? He submitted for Dr. Gough's consideration that the magnesium and other light alloys together with the ordinary steels would have gone to their destruction long before the rustless steels. When Dr. Gough used that expression it was really a scientific figure of speech. The author was greatly indebted for the suggestion with regard to the production of chains for mooring aircraft. He did not know whether it had actually been done—he thought not—but he would look into the matter.

He was sorry that Mr. Fedden had left, because he would have liked to have replied in his presence to the remarks that he had made with regard to the cleanliness of steel. He thought it could be stated without question that practically all the aircraft steel used in the major works in England, was produced in Sheffield. Taking works such as his own, the English Steel Corporation, and Hadfields, where up-to-date practice was applied, the steel was of a very high standard of cleanliness. In most of the large works, steel was actually manufactured under microscopic control and, had Mr. Fedden been present, he was sure that he could have persuaded him that the standards which had been fixed were greatly in advance of those of years ago. He was glad that Mr. Fedden had raised the question of quartering. It was a practice for certain aircraft firms to quarter the ingots. The object of that was to ensure that the unsatisfactory centre in some types of ingot was not present in the ultimate forging.

He could answer his question as to whether the technique of to-day rendered that operation superfluous by saying that, owing to the improvements in the production of ingots, a great quantity of aircraft steel was made to-day without the necessity of quartering ingots, as Mr. Fedden would find on inquiry of the steel makers.

He was delighted to hear Major Buchanan's remarks on the question of specifications in general. He quite agreed that the D.T.D. specifications were of immense service and would have to be continued unless metallurgical progress was to stop.

Of the long list of points raised by Mr. Sutton the most important one upon which he would like to touch was that of machinability. Mr. Sutton said he was very glad to find a steel with a high coefficient of expansion, but it was not complete, because it was not easy to machine. Dr. Hatfield was sure that Mr. Sutton would forgive him, as an old friend, for saying that he thought it wrong that the metallurgical world should be restricted in the development of new forms of steel to what the machine shop could easily machine by the old methods. There was no doubt that high expansion steel could be ground; it could be machined with carbide. They could not, however, confer upon it the same mechanical properties as on other steels which could be machined easily. What was the machining operation? Take a simple turning: The point of the turning did not cut but merely acted as a wedge. It was driven along and by sheer brutality pulled off lumps of metal. To visualise the actual operation brought home at once the fact that the very properties which were introduced into this special steel militated against machining. Other means must be taken, and those means were available. With the development of the super high speed steels and the new cutting carbides, grinding as a machine operation had now attained a very high standard of perfection.

He agreed that it was necessary, as regards the corrosion resisting properties of certain materials, that descriptions as to the degree of resistance should be carefully stated. Deposits of dirt on the surface were very frequently of a much less innocent character than a casual inspection would suggest. Such deposits often contained acid or other chemically active compounds. With some of these chemicals it would never be claimed that they could be completely resistant. The presence of free sulphuric acid and certain chlorides were examples of this. The fact that many of these deposits were of a hygroscopic nature was also a factor influencing the tendency to corrosive attack. Referring to the effects which take place at joints, one had also to remember that the phenomenon of shielding, which had been ably described in the work by Evans (J. Chem. Soc., 1929, pp. 92-110), influenced the preservation of the resistant surface of corrosion resistant steels. Precautions such as were described by Mr. Sutton were obviously necessary to obtain satisfactory performance in the case of certain types of construction. He quite agreed with the latter's remarks on the effect produced by the presence of scale on the surface of the stainless steels. As to the methods of removing such scale, space did not permit to go fully into this question. Suffice it to say that any effective pickling method could be employed, or alternatively, removing the scale by mechanical means such as grinding was also satisfactory. The author thanked Mr. Sutton for his addition to the information as to the behaviour of Duralumin in contact with sea water in contact corrosion tests. The use of some medium to protect the Duralumin in cases of long exposure appeared to be a wise policy. It appeared from Mr. Sutton's remarks on corrosion stress cracking that he was afraid that even the austenitic steels might be unsatisfactory from this point of view when used in a very hard condition. He would point out to Mr. Sutton that the demand for a still harder condition emanated not from the steel makers but from the designers. However, within the range of hardness which was at present being employed with such steels, the question of corrosion stress cracking appeared to be pretty well in hand.

There were plenty of steels available which could meet with the problem adumbrated by Mr. Langley. The maximum stresses were often stronger at lower temperatures than at normal temperatures, and there would be sufficient ductility to do the job. That observation applied to rustless steel just as it did to ordinary steels. If Mr. Langley would specify the parts to which he referred he would be glad to send him information. He could give him the assurance that austenitic steels did not become magnetic at 40 to 50 degrees below zero. He was unable at the moment to be absolutely precise about it, but he thought if they took the austenitic rustless steels down to minus 120 degrees Centigrade they would be found not to have become very magnetic; indeed they had been selected for most important experiments at Cambridge, owing to the fact that they had properties at very low temperatures which were not associated with any other ferrous metal.

Mr. Manning had said that all the slides that had been shown were of crystalline aggregates and that probably the properties were largely the result of the surface contacts of those many crystals.

Mr. MANNING: Dr. Hatfield had evidently misunderstood. What he had said was that the tensile strength of the steel would be that of the weakest of its various constituents.

Dr. HATFIELD: He agreed, and added that Mr. Manning postulated that very likely the single crystal would be the solution of the difficulty.

Mr. MANNING: What would be the strength of the single crystal?

Dr. HATFIELD: A great deal of experimental work had been done on the mechanical properties of single crystals, largely by his friend Dr. Gough, and such evidence as there was showed that from Mr. Manning's point of view very little could be hoped for from the single crystal. In all cases it had a much lower strength, the elastic range was very low indeed, and he would venture the statement that the characteristics of the steels and metals employed in aeroplane and aircraft engine design were really due to the fact that the metal was a crystalline aggregate which had properties suited to Mr. Manning's purposes, which were not found in single crystals. He thought that Dr. Gough would corroborate that statement. He could hold out no hope to Mr. Pollard that metallurgists would be able to give him a modulus of 40 million. They would, however, be able to do much better than a thickness of seven-thousandths of an inch for steel sheet or strip, but that was another story.

The author thanked Mr. Johnson for his communication, particularly with regard to the data on strength-weight ratios of the various materials. In accordance with Mr. Johnson's suggestion some of the values given in Table II had been modified to bring them into line with the minimum figures quoted in the specifications. In reply to the remark on the D.T.D. 49A group of valve steels, it would be noted that these steels, described as austenitic chromium-tungsten valve steels, were included in group S, which occurred at the end of the table. Referring to crankshaft materials, the author had not attempted to make a clear distinction between the two steels coming under the specifications S. 65 and S. 81. These steels were really similar and the preference for one analysis against the other was largely one of individual taste. As regards the comparison of steels S. 62 and S. 80 for fuel pump gears, apart from any question of machinability the latter had some advantage from the point of view of corrosion resistance, but in this item the tendency to corrosion was not very severe and hence the probable greater use of the former material.

With reference to Professor Andrew's communication, Dr. Hatfield expressed his appreciation and general agreement. On the question of the number of steels in production he quite agreed with Professor Andrew's remarks and had himself expressed the same view as far back as 1917 in connection with the earlier paper. At the same time it was necessary, in order that development should not be

impeded, that the way should be left open for new modifications, which in some cases meant only slight changes in composition. Professor Andrew referred to the effect of mass in heat treatment. The data given in the tables referred to the actual forms in which the materials are supplied for aircraft work, chiefly in the form of sheet, strip, wire or bars, the latter usually not exceeding $2\frac{1}{2}$ diameter or thickness. Aircraft components did not generally involve very heavy sections. On the general question as to the separate influence of the various added elements in the more complex steels Dr. Hatfield agreed that there was still an extremely wide field on which much further information was desired.

The CHAIRMAN: It was Bismarck who said that "the nation wins through by blood and iron." He believed that had now been changed to winning through with oil and steel. Consequently the construction of steel was of very great importance. Frankly, as a man in the street, one bit of iron looked very much like another to him, but he could see after reading the paper what an immense study of a specialist type these things necessitated. It had been rightly said that night that this paper would become almost a text book. He only wished that they had with them on that occasion some other type of scientist, perhaps a doctor, who would notice that by mixing something with iron you got rid of fatigue, that by giving it a dose of something else it became hardened up, and by something else one could change its temper. That would be very desirable. The doctor would also be interested in the possibility and desirability of getting pickled! It was a singular thing that iron had those great possibilities of which the human frame was apparently devoid. It was 17 years since they last heard from Dr. Hatfield on this very important subject. The Chairman could see by the general interest taken in the lecture that night that they must not let another 17 years go by before they heard from him again. Work on the subject became cumulative and compressed and he was sure that Dr. Hatfield would be kind enough in a few years' time to tell them of his further discoveries in this very important field.

A THEORETICAL INVESTIGATION OF THE MAXIMUM-LIFT COEFFICIENT *

BY

TH. VON KARMAN[1] and CLARK B. MILLIKAN[2]

In the present paper the application of a laminar boundary-layer theory, previously developed by the authors, to the problem of the maximum-lift coefficient of airfoils is discussed. The calculations are carried through in detail for a first approximation, called a single-roof profile, to the potential velocity distribution over the upper surface of an airfoil. The results indicate a large variation in $C_{L_{max}}$ with turbulence but the quantitative dependence on Reynolds number and turbulence is not satisfactory. The calculations are then repeated for a so-called double-roof profile which approximates to the flow over the upper surface of an N.A.C.A. 2412 airfoil. These results are compared with those obtained from an experimental investigation on the same airfoil. The agreement is considered to indicate that for moderate values of R and $C_{L_{max}}$ the phenomenon of the maximum-lift coefficient is controlled by a contest between the separation and transition points of the laminar boundary layer over the nose of the airfoil. The difficulties involved in extending the theory to larger values of R, or to airfoils whose C_L vs. α curves are not approximately linear up to the stall, are mentioned.

1. INTRODUCTION

The problem of the maximum lift of airfoils has concerned the authors greatly since there were first discovered in the spring of 1932 serious discrepancies in this characteristic between results obtained in the wind tunnel of the Guggenheim Aeronautics Laboratory at the California Institute of Technology (GALCIT) and those reported from certain other wind tunnels. An elaborate experimental investigation by the junior author and A. L. Klein[3] indicated that the value of $C_{L_{max}}$ for a given airfoil was strongly affected both by Reynolds number and by the degree of turbulence in the tunnel wind stream. It had long been known that the maximum-lift behaviour was intimately connected with the separation

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[2] Associate Professor of Aeronautics, Daniel Guggenheim Graduate School of Aeronautics, California Institute of Technology. Assoc.Mem.A.S.M.E. Professor Millikan was born in Chicago in 1903, and received his Ph.B. from Yale University in 1924 and Ph.D. in Physics and Mathematics from California Institute of Technology in 1928. He was a Teaching Fellow at the California Institute of Technology from 1924 to 1928, and since then has been on the staff of the Aeronautics Department of that Institute.

[3] "The Effect of Turbulence: An Investigation of Maximum-Lift Coefficient and Turbulence in Wind Tunnels and in Flight," by C. B. Millikan and A. L. Klein, *Aircraft Engineering*, August, 1933 (London).

of the boundary layer from the upper surface of an airfoil, but it had in general been supposed that for practically important Reynolds numbers this phenomenon involved only the turbulent state of the boundary layer. The great dependence of $C_{L\max}$ on the degree of free-stream turbulence, as revealed by the aforementioned experiments, made the authors suspect that the boundary layer at a separation point may be sometimes turbulent and sometimes laminar. The free-stream turbulence would then have a great influence in determining which of the two régimes was in effect for a particular case, and it is easy to see that the separation phenomenon might be importantly influenced by the possible existence of these alternative types of flow in the boundary layer. It is well known that a turbulent boundary layer resists separation much more effectively than does a laminar one. Hence an early transition of the boundary layer from the laminar to the turbulent state, induced by large external turbulence, might delay the separation and increase the maximum lift. The quantitative discussion of such an hypothesis requires an analysis of the laminar boundary layer, and in particular a determination of its separation point and its thickness at that point.

The existing methods for the calculation of a laminar boundary layer with a more or less arbitrary pressure distribution were felt to be unsatisfactory for this purpose. Accordingly, an entirely new procedure was developed which has been presented in detail in a previous paper by the authors.[4] In the present paper the application of this boundary layer analysis to the problem of the maximum-lift coefficient will be discussed. The explicit aim of this paper is, then, to investigate the dependence of $C_{L\max}$ on Reynolds number and free-stream turbulence over the regions available for normal wind tunnel tests.

2. Outline of the Basic Procedure[5]

The boundary layer theory is based on the assumption that the influence of friction is restricted to the neighbourhood of the walls and does not essentially change the outside flow. Its application is, therefore, restricted to those cases in which the outside flow is known. Hence, we are able to investigate whether or not a given flow pattern about an airfoil, involving a certain magnitude of the lift and a certain pressure distribution, is possible without separation of the flow from the surface, but we are not able to determine flow patterns with separation.

In view of the restricted possibilities of the theory we are led to a kind of inverse method to determine the maximum value of the lift coefficient C_L as a function of Reynolds number and the degree of turbulence. We start with a given value of C_L and inquire whether or not the potential flow which would produce the assumed lift in a non-viscous fluid can be maintained in a viscous fluid without separation, *i.e.*, whether or not the influence of the friction will be restricted to the boundary layer.

It is easily seen that the problem put in this form is not quite identical with the original problem of the maximum lift. Let us neglect for a moment the possibility of turbulence in the boundary layer. Then the possible values of C_L would be given by flow patterns which do not lead to separation of the laminar boundary layer, and the limiting values of C_L would correspond to the flow with separation just at the trailing edge. Now it is a well known result of the laminar boundary layer theory that for geometrically similar bodies the location

[4] "On the Theory of Laminar Boundary Layers Involving Separation," by Th. von Kármán and C. B. Millikan, N.A.C.A. Technical Report No. 504.

[5] Condensed accounts of portions of the discussion of this section have already been presented by the authors; *cf.* "Quelques Problemes Actuels de l'Aerodynamique," by Th. von Kármán, Journees Techniques Internationales de l'Aeronautique, Paris (1932). "The Effect of Turbulence: An Investigation of Maximum-Lift Coefficient and Turbulence in Wind Tunnels and in Flight," by C. B. Millikan and A. L. Klein, *loc. cit.* "The Use of the Wind Tunnel in Connection with Aircraft-Design Problems," by Th. von Kármán and C. B. Millikan, Trans. A.S.M.E., 1934, pp. 151-166, paper AER-56-4.

of the separation point is independent of the Reynolds number. Thus we should conclude that $C_{L\max}$ determined in this way gives only an inferior limit, because flow patterns with separation may give higher lifts than those with separation at the trailing edge, but it is certain that any value below this calculated $C_{L\max}$ can be reached without separation. For this reason the actual values of $C_{L\max}$ may be higher than those determined from the " no separation " criterion, and may be variable with Reynolds number.

Fortunately, the case in which the boundary layer is laminar along the whole or a considerable part of the airfoil is without practical importance. In the practical range of Reynolds numbers, both in the case of full-scale airfoils in flight and in that of normal wind tunnel tests, the laminar régime is restricted to a small portion of the chord. Hence, if the laminar boundary layer separates from the airfoil before transition to the turbulent régime occurs, the separation occurs not far from the leading edge. Such a separation must clearly lead to an abrupt drop in the lift coefficient, such as experiments actually reveal. As a matter of fact, for most modern " efficient " airfoil sections, the experimental $C_L = f(\alpha)$ curves (α = angle of attack) are almost straight up to the stalling point, as would be the case for the pure potential flow, and show a more or less sharp break at the stalling point. Thus in the practically important range we can assume that C_L values which lead to separation of the laminar layer prior to the change to the turbulent state are impossible for such airfoils. Our considerations may, however, not be valid for airfoils in which the C_L vs. α curves have a considerable curvature well before the stall is reached.

Before discussing the second alternative, that the laminar layer becomes turbulent before it reaches the separation point, let us review briefly the pertinent experimental facts for the boundary layer along a flat plate placed parallel with a uniform flow. It is convenient to introduce two Reynolds numbers for such a boundary layer flow. The basic flow Reynolds number R is defined in terms of the characteristic length of the problem, *i.e.*, the length of the plate or airfoil in the direction of flow, and of the free stream velocity far from the airfoil or plate. The boundary layer Reynolds number R_δ is defined in terms of the boundary layer thickness δ at any point along the surface, and of the velocity just outside the boundary layer at this point. The two definitions are $R = U_0 t/\nu$ and $R_\delta = U\delta/\nu$ where U_0 is the undisturbed velocity, t the chord of airfoil or plate, U the potential velocity just outside the boundary layer, δ the boundary layer thickness at the same point along the surface, and ν coefficient of kinematic viscosity. The definition of the boundary layer thickness is somewhat arbitrary, but using the same definition throughout the discussion, the results are independent of the definition.

For the flow along a flat plate which we are discussing for the moment, the boundary layer starting from the upstream edge of the plate is laminar in character even though the outside flow is highly turbulent or fluctuating. The boundary layer thickness increases continuously as one goes downstream from the leading edge, so that the boundary layer Reynolds number R_δ varies in the same way. For any given type of turbulence or fluctuations in the outside flow there exists a certain value of R_δ at which the laminar régime in the boundary layer becomes unstable and a transition occurs to a turbulent state of flow. Actually there is a region of finite length along the plate in which this transition from the laminar to the so-called " fully developed " turbulent régime takes place. For simplicity in both discussion and calculation it is, however, customary to assume that the transition is instantaneous and occurs at a definite point which we shall refer to as the transition point, and which will be indicated by a subscript $(\,)_t$. The boundary layer Reynolds number at which the transition occurs is called the critical Reynolds number and will be denoted by $R_{\delta c}$. The variation of R_δ with the basic Reynolds number of the flow, at a given point along the plate, is given by the relation $R_\delta \sim \sqrt{R}$. Assuming the state of turbulence in the outer flow

to be independent of the value of R, it follows that for a given air stream $R_{\delta c}$ is also independent of R. Consequently, the transition point, *i.e.*, the point at which R_δ reaches the value $R_{\delta c}$, moves upstream along the plate as R increases. The conditions for two values of R are indicated schematically in Fig. 1. $R_{\delta c}$

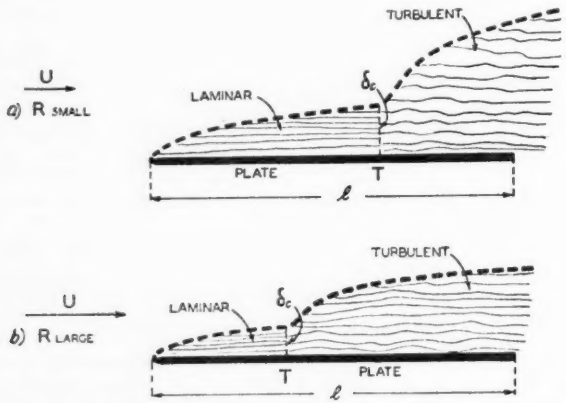


FIG. 1 THE BOUNDARY LAYER ALONG A FLAT PLATE AT TWO REYNOLDS' NUMBERS

is experimentally found to be independent of R for a given air stream, but to vary with the degree of outside turbulence in such a way that it decreases as the turbulence increases. The observed values of $R_{\delta c}$ lie between about 10,000 for very smooth flows and 1,500 for very turbulent flows.

We assume, with considerable experimental justification, that very similar phenomena occur for the boundary layer over the upper surface of an airfoil. In other words, for any given external air flow there is a definite value of $R_{\delta c}$ such that, when the boundary layer Reynolds number reaches this value, there is a transition point downstream from which the airfoil boundary layer is turbulent, while upstream it is laminar.

We have already discussed the case in which the laminar layer separates before the change to the turbulent régime. This will obviously take place if, for the calculated Reynolds number of the laminar layer at the separation point $R_{\delta s}$, we have the inequality $R_{\delta s} < R_{\delta c}$. In the opposite case when $R_{\delta s} > R_{\delta c}$, the layer becomes turbulent before separation and whether or not the value of C_L considered can be reached, obviously depends on the behaviour of the turbulent layer. Unfortunately, the theory of the turbulent boundary layer is not as yet so far advanced as to furnish a definite answer to this question. However, it is well known that the turbulent layer exhibits a considerably higher resistance to separation than does the laminar layer. Hence we consider first the idealised case that the turbulent layer clings under all circumstances to the airfoil surface, *i.e.*, we neglect the possibility of separation for the turbulent layer. This neglecting of the possibility of separation of a turbulent boundary layer implies that as $R \to \infty$ indefinitely large values of C_L could be reached, and obviously imposes limitations on the range of validity of the theory. We discuss this in more detail in a later section of this paper, entitled " Comparison with Experiment and Region of Validity of the Theory."

With this assumption (no separation of a turbulent boundary layer) the following procedure leads to a family of $C_{L\max}$ curves giving $C_{L\max}$ as a function of Reynolds number for different degrees of turbulence in the outside stream: We start with an assumed potential velocity distribution corresponding to a

definite value of C_L. From this we calculate the laminar separation point, which will occur at a fixed point on the upper surface of the airfoil. The corresponding value of $R_{\delta s}$ will be proportional to $\sqrt{R}$. We now consider an external flow with a definite degree of turbulence so that $R_{\delta c}$ has a definite value independent of R. If we start with small enough values of R then $R_{\delta s}$ will be less than $R_{\delta c}$, separation will occur, and the boundary layer will behave as in (*a*) of Fig. 2.

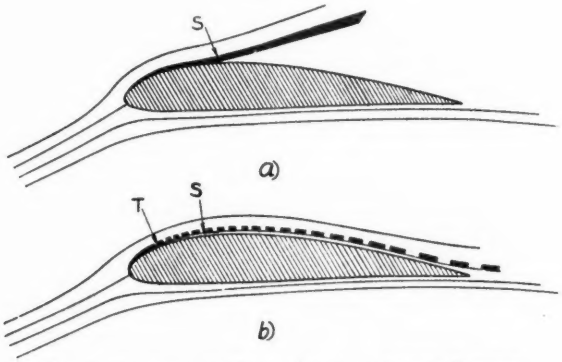


FIG. 2 ALTERNATIVE FLOWS ABOUT AN AIRFOIL SECTION

The assumed potential flow can obviously not occur and the assumed C_L will not be obtainable. If, now, we increase R, $R_{\delta s}$ increases continuously until it finally equals and then surpasses the constant value of $R_{\delta c}$.

We can alternatively describe this process in the following way: For small values of R, the transition point is downstream from the separation point (case *a*); with increasing R, the transition point moves upstream, while the location of the separation point is independent of R. When $R_{\delta s}=R_{\delta c}$, the two points coincide. A still further increase of R leads now to case (*b*), *i.e.*, the boundary layer at the calculated separation point is turbulent and so clings to the airfoil surface, the assumed potential flow can occur and the assumed C_L is reached. If we repeat the calculations for a series of potential velocity distributions (*i.e.*, lift coefficients), we get a definite value, of R for each C_L, above which the C_L value is attained and below which it is not. Plotting C_L against R we therefore obtain a curve giving the maximum C_L which can be obtained at any R for a given type of air flow. Again repeating for other values of $R_{\delta c}$ we finally get a family of curves giving $C_{L\max}=f(R)$ for a series of flows characterised by different amounts of external turbulence.

3. BOUNDARY-LAYER NOTATION EMPLOYED

In the following sections we consider the application of the procedure just described to certain special cases. The laminar boundary layer characteristics are determined using the boundary layer theory given in the preceding paper by the authors (*loc. cit.*). The conventions adopted in the preceding paper will also be followed here and are the following: All quantities are dimensionless, lengths being divided by the characteristic length which is taken as the airfoil chord, and velocities being divided by the characteristic velocity taken as the free stream velocity far from the airfoil. The basic Reynolds number R is then defined in terms of these characteristic quantities. The dimensionless potential velocity just outside of the boundary layer is denoted by U, the dimensionless distance measured along the upper surface of the airfoil from the stagnation point by x, and the dimensionless boundary layer thickness by δ. R_δ, the

boundary layer Reynolds number, is defined in terms of the actual boundary layer thickness and the actual potential velocity just outside of the boundary layer at an arbitrary point along the surface. The subscripts $(\ )_s$ and $(\ )_t$ denote, respectively, separation point (of the laminar layer) and transition point (from the laminar to the turbulent régime). $R_{\delta c}$ is the value of R_δ at which the transition occurs, and is a constant for a particular external flow.

In the boundary layer analysis mentioned above it is found convenient to introduce an alternative variable, in addition to x, to give the distance downstream from the stagnation point along the airfoil upper surface. This variable is defined by $\phi = \int_0^x U dx$ and is identical with the value of the external flow potential function at the point x. In the paper mentioned, formulas are given for determining the separation point and the value of $R_{\delta s}$ for the laminar boundary layer corresponding to any function $U^2(\phi)$ which may be represented by one or two polynomials in ϕ. In the succeeding sections two general types of such flows are considered in detail.

4. The "Single-Roof" Profile

The " single-roof " profile, represented in Fig. 3, is a first, crude approxima-

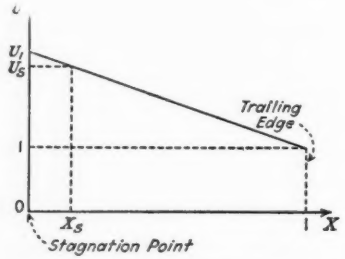


Fig. 3 The Single-Roof Profile
$U = U(x)$

tion to the potential flow distribution over the upper surface of an airfoil. It is developed by assuming that the velocity is a linear function of the distance downstream from the stagnation point, while the rapid increase in the velocity from zero to its maximum value U_1 is replaced by a discontinuous jump. It is also assumed that the stagnation point coincides with the leading edge; so that $x=1$ corresponds to the trailing edge. It will be noticed that the velocity at the trailing edge has been taken equal to the undisturbed free stream velocity, so that U (trailing edge) $=1$. The latter restriction was imposed after a study of the calculated potential velocity distributions around several airfoils, and is in good accordance with the corresponding experimental velocity distributions.

The single-roof profile has two advantages, first the boundary layer calculations are especially simple, and second, plausible assumptions lead to a very easy determination of C_L as a function of the maximum velocity U_1. The assumption which was made in the latter connection was that the upper surface contributes all of the lift, *i.e.*, the average pressure over the bottom surface is the same as that at the upper surface trailing edge, which in turn equals the static pressure far from the airfoil. From this assumption, and using the Bernoulli theorem, we easily obtain the relation

$$C_L = \tfrac{1}{8}(U_1 - 1)(U_1 + 2) \quad . \quad . \quad . \quad . \quad . \quad (1)$$

connecting C_L and the maximum velocity U_1.

Turning now to the application of the boundary layer analysis to this single-roof profile, we shall make use of results presented in the previous paper by the authors (*loc. cit.*), in which the laminar boundary layer theory is worked out in some detail for this example. Equations (38) and (41) in the paper cited, furnish the result that the laminar separation point occurs at the position along the surface where $U_1^2/U^2 = 1.241$, *i.e.*,

$$U_s = 0.897\ U_1 \qquad . \quad . \quad . \quad . \quad . \quad (2)$$

In addition, equations (44) give the value of the boundary layer Reynolds number at this separation point as

$$R_{\delta s} = 2.18 \frac{U_1}{\sqrt{U_1 - 1}} \sqrt{R} \qquad . \quad . \quad . \quad . \quad (3)$$

These are the only results of the laminar boundary layer analysis which we shall need in this section.

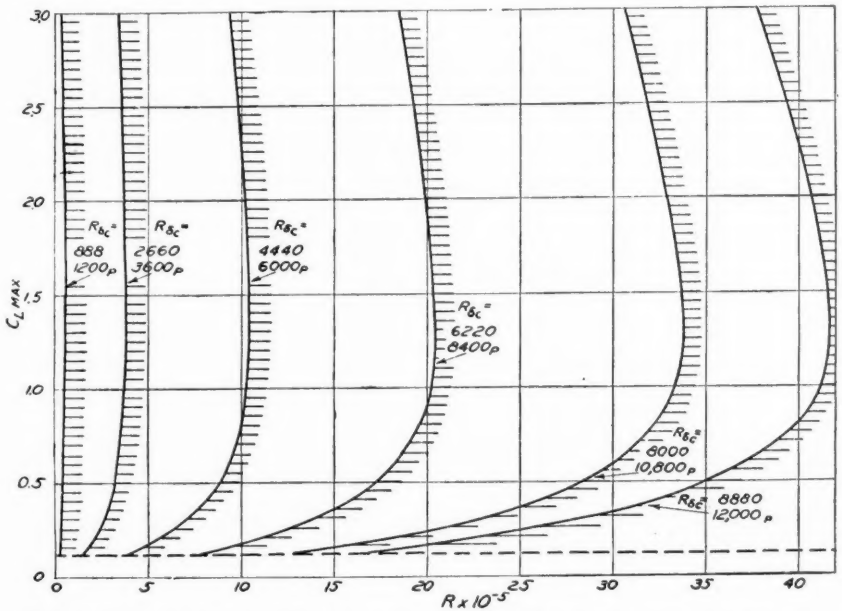


FIG. 4 $C_{L\max}$ AS FUNCTION OF R AND EXTERNAL TURBULENCE FOR THE SINGLE-ROOF PROFILE

If U_s as given by equation (2) is less than 1 there is obviously no separation point on the airfoil surface. Hence $U_1 = 1/0.897 = 1.115$ is a limiting value below which the flow always clings to the airfoil without separation. The corresponding value of C_L from equation (1) is $C_L = 0.120$. Hence $C_{L\max} = 0.120$ is a lower limit which can always be reached for a flow without separation, no matter how small the Reynolds number. (The Reynolds number must, of course, be large enough so that the basic assumptions of the boundary layer theory remain valid.) If the possibility of a turbulent boundary layer were excluded this would also be the largest possible value of $C_{L\max}$ according to our simplified assumptions for the phenomenon as they were outlined in section 2, " Outline of the Basic Procedure." However, the assumptions already discussed regarding the transition to and behaviour of a turbulent boundary layer alter the matter completely, and require a more elaborate analysis to obtain values of $C_{L\max}$.

In the following paragraph we shall outline the calculations leading to the determination of these values.

We remember that for a given degree of turbulence in the external flow there exists a definite value of $R_{\delta c}$. For a fixed value of U_1 (*i.e.*, of C_L) $R_{\delta s}=R_{\delta c}$ is a limiting case such that this C_L is just achieved. If R is decreased $R_{\delta s}$ is decreased and the assumed value of C_L is not reached. Conversely, if R is increased the assumed C_L will always be realised. In order to determine this limiting case we actually calculate $R_{\delta s}/\sqrt{R}$ as a function of C_L from equations (1) and (3). Then putting $R_{\delta s}$ equal to a series of numerical values $R_{\delta c}$, we obtain a corresponding series of functions $R(C_L)$ or $C_L(R)$. The curves of C_L vs. R determined in this way are really curves of $C_{L\max}$ vs. R for various degrees of external turbulence, since each curve gives a definite value of R above which a given value of C_L will always be reached and below which it can never be reached. The results of such a calculation are plotted in Fig. 4, the regions in which a given C_L can be attained being indicated by the cross-hatching at one side of the curves. The values of $R_{\delta c}$ are given by the numbers without subscripts and represent various degrees of external turbulence. Thus 1,000 corresponds to a high degree of turbulence and 10,000 to a low degree.

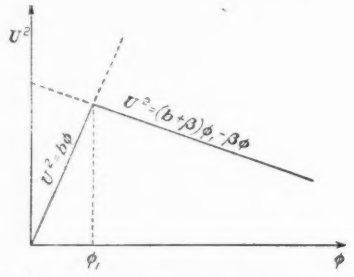


FIG. 5 THE DOUBLE-ROOF PROFILE, $U^2 = U^2(\varphi)$

The results are very interesting in that they reveal an extremely large dependence of $C_{L\max}$ on external turbulence, so that our basic conception of the phenomenon is, to some extent, justified. However, the dependence on Reynolds number is entirely unsatisfactory and indicates that the single-roof profile is too crude an approximation to yield any quantitative results.

Before passing on to the refinements required to improve the results, it might be mentioned that the familiar Pohlhausen boundary layer method may be simply applied to this case. The boundary layer analysis has already been given by the authors (*loc. cit.*), and the application of the results to the $C_{L,\max}$ problem follows exactly the procedure just discussed. It is easy to see that identically the same curves are obtained as followed from our boundary layer theory. The only difference is that the values of $R_{\delta c}$ associated with a particular curve are different for the two methods. The Pohlhausen values have been included in Fig. 4 with a subscript $(\ )_p$.

5. THE "DOUBLE-ROOF" PROFILE AND ITS APPLICATION TO THE MAXIMUM-LIFT ANALYSIS OF THE N.A.C.A. 2412 AIRFOIL

It has been mentioned above that the authors' boundary layer analysis has been developed for external flows such that $U^2(\phi)$ may be represented by one or two polynomials in ϕ. The single-roof profile corresponds to one of the simplest cases of such a flow, *i.e.*, U^2 is given by a single linear function of ϕ. In the present section we consider a somewhat more complicated case in which U^2 is

given by two linear functions of ϕ, and there is an actual stagnation point at the origin of x. Such a flow may be described analytically as follows:—

$$\left.\begin{array}{l}\text{For } 0 \leqslant \phi \leqslant \phi_1;\ U^2 = b\phi \\ \text{For } \phi_1 \leqslant \phi;\ U^2 = (b+\beta)\phi_1 - \beta\phi\end{array}\right\} \quad . \quad . \quad . \quad (4)$$

where ϕ_1 is a fixed value of ϕ, and b and β are positive constants. We call such a velocity distribution a " double-roof " profile, the reason being obvious from Fig. 5 where the profile has been represented schematically by the full lines.

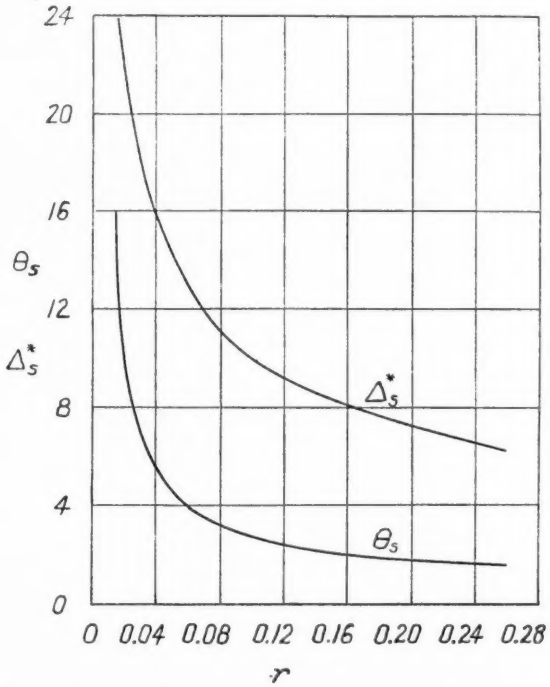


FIG. 6 GENERAL FUNCTIONS GIVING SEPARATION-POINT CHARACTERISTICS FOR THE DOUBLE-ROOF PROFILE

For our present purposes we need only two results of the boundary layer analysis, which, just as in the case of the single-roof profile, are the position of the laminar separation point ϕ_s, and the value of the boundary layer Reynolds number at this point, $R_{\delta s}$. From section 14 of the earlier paper we obtain

$$\left.\begin{array}{l}\phi_s = \phi_1\theta_s \\ R_{\delta s}/\sqrt{R} = \sqrt{\phi_1}\Delta^*_s\end{array}\right\} \quad . \quad . \quad . \quad . \quad (5)$$

where θ_s and Δ^*_s are given in Fig. 6 as functions of $r = \beta/b$. The necessary laminar boundary layer characteristics are accordingly given in terms of the double-roof parameters ϕ_1 and r.

The experimental investigation of the maximum lift phenomenon mentioned at the beginning of the paper dealt with wind tunnel measurements on a rectangular airfoil with the N.A.C.A. 2412 profile whose ordinates and general

characteristics have previously been published.[6] It was natural, therefore, to base the theoretical considerations upon the same airfoil section, which is a very efficient one of moderate thickness and small camber. Accordingly the potential-velocity distribution over the 2412 profile for a two-dimensional flow was calculated by Theodorsen's method for a series of values of airfoil lift coefficient C_L. Since Theodorsen's method has been described in extenso[7] no details of the calculation will be repeated here. For the problem in hand we require only the velocity distribution over the upper surface of the airfoil for some distance downstream of the separation point. The functions $U^2(\phi)$ determined for this region are given by the full lines of Fig. 7, corresponding to calculated values of C_L

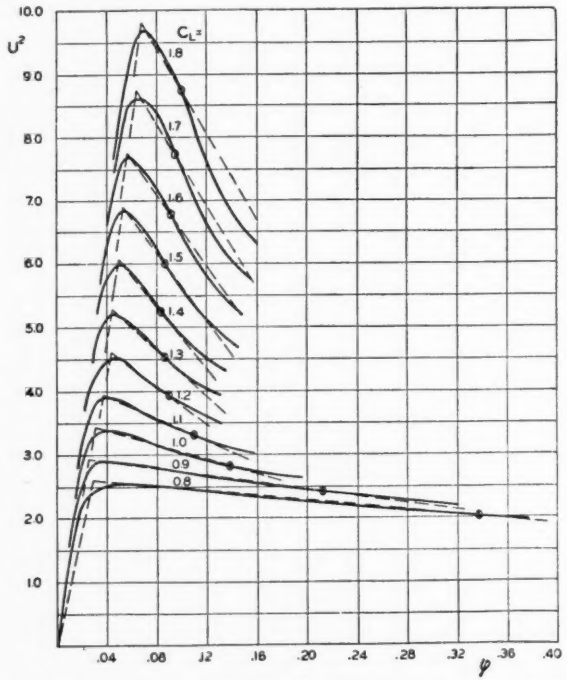


FIG. 7 POTENTIAL-VELOCITY DISTRIBUTIONS FOR THE N.A.C.A. 2412 AIRFOIL, AND THE APPROXIMATING DOUBLE-ROOF PROFILES

from 0.8 to 1.8. For the sake of clearness the curves are not extended quite down to the stagnation point origin.

It appears that all of the functions $U^2(\phi)$ given in Fig. 7 can be fairly satisfactorily approximated by double-roof profiles for the region upstream from the separation point. Such an approximation seems to be especially justified by the fact that the main purpose of the investigation is to discover the physical bases for the variation of $C_{L\max}$ with turbulence and Reynolds number rather than to deduce the precise quantitative dependence of $C_{L\max}$ on these two variables. All

[6] "Tests of N.A.C.A. Airfoils in the Variable Density Wind Tunnel, Series 24," by E. N. Jacobs and K. E. Ward. N.A.C.A. Technical Note No. 404, January, 1932.

[7] "Theory of Wing Sections of Arbitrary Shape," by Theodore Theodorsen. N.A.C.A. Technical Report No. 411 (1932).

the further calculations are, therefore, made with double-roof profiles chosen so as to approximate as closely as possible to the solid curves of Fig. 7 between the stagnation and separation points. The double-roof profiles are indicated by the dotted lines in Fig. 7, and the oval symbols give the values of ϕ_s as determined from equations (5) and Fig. 6. $R_{\delta s}/\sqrt{R}$, obtained in the same way, is plotted as a function of C_L in Fig. 8.

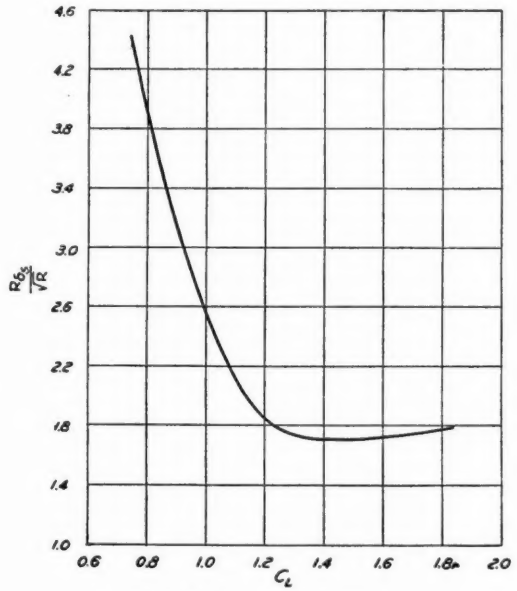


FIG. 8 $R\delta_s/\sqrt{R}$ VS. C_L FOR 2412 AIRFOIL

Using Fig. 8, curves of $C_{L\max}$ vs. R are determined for various degrees of external turbulence in exactly the same manner as was outlined in section 4 for the single-roof profile. It is only necessary to equate $R_{\delta s}$ to a series of constant values of $R_{\delta c}$, characterising the degree of external turbulence, and then to determine from Fig. 8 the values of R at which a given C_L is just attained. The final results are plotted in Fig. 9 as solid curves.

6. COMPARISON WITH EXPERIMENT AND REGION OF VALIDITY OF THE THEORY

Before discussing the theoretical results, it will be desirable to consider the results of the experimental investigation of the same problem, to which reference has already been made. As has been stated, the experiments were performed in the Guggenheim Aeronautics Laboratory at the California Institute of Technology wind tunnel on a model of the N.A.C.A. 2412 airfoil. In order to obtain a series of degrees of turbulence a wire grid or screen was placed at a number of distances upstream from the model. With the grid close to the model the degree of turbulence at the airfoil is high, with the grid far away the turbulence is low. At each position of the grid measurements were taken at from six to fifteen different Reynolds numbers. The results as far as $C_{L\max}$ is concerned are

presented in Fig. 10. Each curve corresponds to a grid position, *i.e.*, to a given degree of turbulence and therefore to a definite value of $R_{\delta c}$. In other words, the curves are directly comparable with those of Fig. 9. It should be noted that the degree of turbulence for each of the curves of Fig. 10 has been indicated by giving the critical Reynolds number R_c, at which a sphere has a drag coefficient[8] $C_D=0.3$. Just as in the case of $R_{\delta c}$, a low value of R_c corresponds to a high degree of turbulence and vice versa.

Comparing the two figures we see that for $C_{L\max} \leq 1.2$ the theoretical curves for $1{,}000 \leq R_{\delta o} \leq 1{,}900$ exhibit a very similar character to the four experimental curves. In this region then the theory gives a qualitatively satisfactory prediction of the dependence of $C_{L\max}$ on R and free stream turbulence. Above $C_L = 1.2$

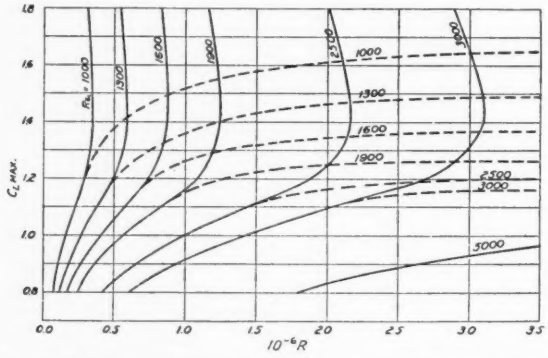


FIG. 9 THEORETICAL CURVES GIVING $C_{L\max}$ AS FUNCTION OF R AND EXTERNAL TURBULENCE FOR THE 2412 AIRFOIL

the theory diverges more and more from experiment. In section 2 it was pointed out that one of the basic assumptions of the theory, namely, that of the non-existence of a separation point for a turbulent boundary layer, implied that infinitely large values of $C_{L\max}$ could theoretically be reached. It is obvious that this assumption represents a considerable over simplification, since it is quite certain that somewhat similar laws actually govern the separation of laminar and turbulent boundary layers. The portions of the theoretical curves which are concave upward or have negative slopes are believed to be in error because of this over simplification in the basic assumptions of the theory. The dotted curves of Fig. 9 represent the authors' judgment as to the nature of the curves which would be obtained if it were possible to determine the separation point characteristics of a turbulent boundary layer. The relatively low values of $R_{\delta c}$ for the theoretical curves which furnish the best approximation to the experimental results are not at all surprising when the unstable nature of boundary layer profiles near a separation point is remembered.

The comparatively good agreement between the theoretical and experimental curves for moderate values of $C_{L\max}$ and R, as well as the quite understandable nature of the discrepancies at higher values of $C_{L\max}$ or R, seems to demonstrate conclusively that the physical basis for the large dependence of $C_{L\max}$ on these two parameters, in the normal wind tunnel range, has been correctly determined as residing in a kind of contest between the separation point of the laminar boundary layer over the upper surface of an airfoil, and the transition point to a turbulent boundary layer régime. This is physically the same picture

[8] "Effect of Turbulence in Wind Tunnel Measurements," by H. L. Dryden and A. M. Kuethe. N.A.C.A. Technical Report No. 342, 1929.

as was used by Prandtl many years ago to explain the phenomenon of the sudden drop in the drag coefficient of a sphere and its dependence on external turbulence and Reynolds number.

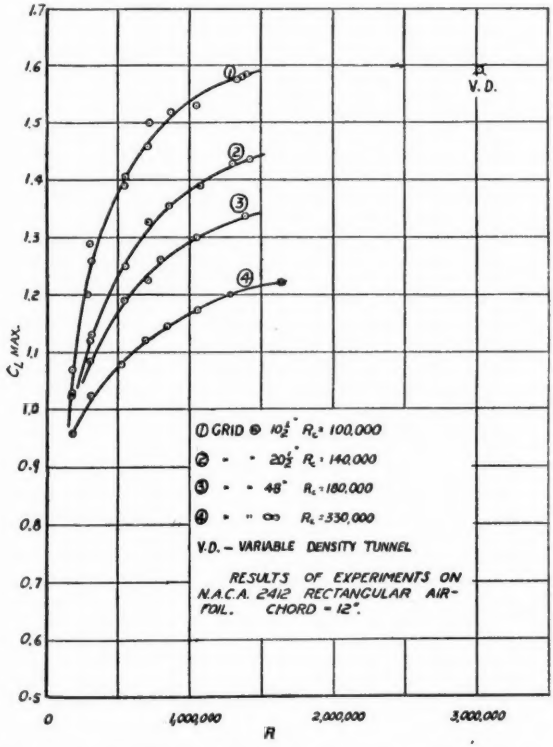


FIG. 10 EXPERIMENTAL CURVES CORRESPONDING TO FIG. 9, TAKEN FROM WIND-TUNNEL TESTS ON A 2412 AIRFOIL

The extension of the present theory so as to obtain valid results for large values of $C_{L\max}$ and of R depends upon the development and application of a satisfactory theory of the separation characteristics of a turbulent boundary layer, and such a theory has, unfortunately, not yet been developed. The discussion of airfoils whose lift does not increase approximately linearly with angle of attack up to the stall would appear to present still further difficulties, but such airfoils are not widely used in practice and consequently are not of great immediate interest.[9]

[9] It might be mentioned that, since the present paper was written, additional experiments have been made and reported by one of the present authors ("Further Experiments on the Variation of the Maximum-Lift Coefficient with Turbulence and Reynolds Number," by Clark B. Millikan, A.S.M.E. Transactions, November, 1934.) These experiments were made with rather unconventional airfoil profiles, whose lift curves had considerable curvature below the stall. As might have been expected, the dependence of $C_{L\max}$ on Reynolds number and turbulence was quite different from that for conventional airfoils like the 2412. The desirability of an extension of the present theory in order to explain the maximum-lift phenomenon for some unconventional profiles has, therefore, been experimentally demonstrated.

7. Conclusions

In the present paper the application of a laminar boundary layer theory previously developed by the authors to the problem of the maximum-lift coefficient of airfoils is discussed. The calculations are carried through in detail for a first approximation, called a single-roof profile, to the potential velocity distribution over the upper surface of an airfoil. The results indicate a large variation in $C_{L\max}$ with turbulence but the quantitative dependence on Reynolds number and turbulence is not satisfactory. The calculations are then repeated for a so-called double-roof profile which approximates to the flow over the upper surface of an N.A.C.A. 2412 airfoil. These results are compared with those obtained from an experimental investigation on the same airfoil. The agreement is considered to indicate that for moderate values of R and $C_{L\max}$ the phenomenon of the maximum-lift coefficient is controlled by a contest between the separation and transition points of the laminar boundary layer over the nose of the airfoil. Finally, the difficulties involved in extending the theory to larger values of R, or to airfoils whose $C_{L\max}$ vs. α curves are not approximately linear up to the stall, are mentioned.

REVIEWS

Our Future in the Air

By Brigadier-General P. R. C. Groves, C.B., C.M.G., D.S.O. Published by George G. Harrop, Ltd. Price 2/6.

General Groves has very definite views on the subject of civil aviation as it affects this country. He naturally desires to see the British Empire supreme in all matters concerning the air, and the weapon he proposes to use to attain this is the subsidy. It is not by any means certain that he is right.

Reviewing the civil air situation generally, it is an interesting fact that those air services which are nearest to paying their own way unassisted are those which receive the minimum subsidy, from which it would seem to follow inevitably that the efficiency of a service depends on the extent to which the operators know that they have to rely on their own efforts. If the choice is between efficiency and a subsidy, efficiency would seem preferable to those who believe that civil aviation is best run on a business basis.

But there is an additional point of view, it may be considered necessary to use an unsuitable type of civil aircraft, to use them in unnecessary numbers, and to fly them over routes which are unprofitable solely because an unsuitable type of civil aircraft may be extremely suitable for war purposes when certain prearranged alterations and additions have been made. Under these circumstances a heavy subsidy is necessary, as it would be if it were proposed to utilise H.M.S. " Hood " by removing her guns and running her commercially between London and the Antipodes with her ammunition rooms full of New Zealand mutton. But the whole process is evidently based on inefficiency and it is at least questionable whether better value for the money could not be obtained by applying it directly to military aviation. If mere numbers of civil aircraft are of military interest, they can be best encouraged by inducing manufacturers to produce machines which can be operated cheaply, thereby assisting operators to cheapen fares and open up new routes. That this is possible without a subsidy has been shown by recent developments in this country.

The second part of General Groves' book is concerned with military aviation and he stresses strongly the case for an increased Air Force. Recent developments have shown that the Government agrees with him and the determination to maintain the Royal Air Force in at least equal strength to that of any neighbour is sufficient to ensure that we cannot be attacked with impunity. Defence against hostile bombing attacks is certainly a most difficult problem, but it is not insoluble and a modern bombing formation is a much better artillery target than a single aeroplane. Incidentally, is it really true, as stated, that a shell takes a minute to reach 20,000ft., the average velocity being only 330 foot-seconds?

General Groves always writes interestingly about such matters and it is hoped that this book will have a wide sale among the general public, but there is certainly scope for a book which will give the other side of the picture. We have been told so often what will happen to London if it is attacked by a hostile bombing formation that we deserve some information about the unpleasant things which will happen to the hostile bombers, but it is probable that this could not be done without divulging official secrets.

Through the Weather House

By R. A. Watson Watt. Published by Peter Davies. Price 7/6.

Mr. Watson Watt is a well-known meteorologist and his book is a laudable attempt to enable the ordinary man to obtain, pleasantly and easily, some of the information about the atmosphere which has been revealed by modern science.

His endeavour is to write a description that will form a picture in the mind of the reader of the cause and nature of atmospheric phenomena, not only with regard to the comparatively thin layer at the bottom which provides the weather, but also with regard to those regions, many miles higher up, which are only known to us through auroral manifestations and their effect on the direction of wireless waves. In order to do this he compares the atmosphere to a house of many stories. As modern theories indicate that changes in condition occur with remarkable suddenness at certain known heights, the analogy fits the conditions remarkably well.

Much of the book is naturally devoted to the weather. Here the author writes clearly, and no one who reads the book intelligently can fail to learn something about the more important of the causes which decide such questions as whether it is going to rain to-morrow. Complete understanding of these matters has not yet been attained by anyone, though in the opinion of one well-known meteorologist, a battalion of computers might calculate to-morrow's weather in six weeks of labour.

In one of the final chapters what are called " housekeeping " matters are discussed on the basis of the cost of electrical energy generated in power stations. It seems, on this basis, that the cost of an hour's sunshine over the British Isles is some £133,000,000,000, and that it would cost £1,500,000,000 to provide the county of Middlesex with its annual rainfall. Such figures bring home to the mind the immense amount of energy involved in meteorological matters.

Talking about lightning, the author remarks that voltages of 10,000,000 or more are involved. As flashes of over half a mile are known to occur, the voltage involved in the phrase " or more " must exceed, possibly by 100 times, the original ten million. He also remarks that the height of the patch of silvery brightness above the setting sun can be measured by holding out a stick 14 inches long at arm's length, and then stops. I wish he had told us how this is done.

The book is an excellent one in every way and is an outstanding example of what can be accomplished when an expert on a subject makes a serious attempt to make its main principles clear to the uninitiated.

Model Aircraft

By W. Rigby. Published by Oxford University Press. Price 1/-.

This book is intended to perform the useful task of teaching boys how to build model aircraft. It is too short to be really adequate, but the author has included a chapter giving quite a full account of how a particular type is constructed.

Having had a certain experience with these matters, and having seen and supervised the building of models by boys, I am certain that Mr. Rigby underrates the intelligence of his prospective readers, who are quite capable of absorbing simple technical facts expressed in simple technical language. It is not necessary to insert new terms such as " wing-slant " for the angle of incidence or " wing-tilt " for dihedral angle; the correct terms are less confusing than the new, and those who are interested in aeronautics will gain from learning to speak the correct language of the subject. But Mr. Rigby sometimes uses descriptions which are simply unintelligible, as when he describes a propeller with

" very coarse pitch, but with the wing tips negatived or turned in at right angles to propeller shaft, thus nullifying a ratio of what might be excessive engine torque on account of the coarse pitch." This statement, and others, suggest that on such matters Mr. Rigby does not know what he is talking about.

His details of methods of construction are, however, good, and he has obviously had much practice in the matter, but I have looked in vain in the book for a drawing of an effective wing section. Why not give ordinates of, say, Clark Y and tell your readers how to use them. Nine boys out of ten will understand without difficulty.

Journées Scientifiques et Techniques de Mécanique des Fluids

Editor, Étienne Chiron, Paris. Two volumes.

This book owes its being to the desire of the Lille Roubaix Tourcoing section of the Society of Civil Engineers of France to celebrate the opening of an institute dealing with the mechanics of fluids at the University of Lille. It consists of a number of papers by authors who are eminent in their particular subject dealing with a large number of matters, such as vacuum pumps and pressure pumps, the conditioning of air, propellers, hulls, and several other matters, including a most interesting paper on the results of wind tunnel tests on chimney cowls which contains information which might prevent many an English chimney from smoking.

The aeronautical papers are all in the first volume. There is one by M. Lapresle on airscrews, one by M. Louis Breguet on rotating wings, and M. Pris discusses lift-increasing devices such as flaps and slots. Among others there is an interesting paper by M. Jarry of the Potez firm on interference.

The book is a useful addition to an aeronautical library, not only because of its aeronautical contents, but because of the amount of general information it contains on methods of using fluids.

Structural Design of Metal Airplanes

By John C. Younger. Published by McGraw-Hill Publishing Co., Ltd.

The author of this book is Professor of Mechanical Engineering at the University of California, and it is of considerable interest as indicating the American outlook on aircraft construction. It is not by any means an ordinary text book, for much that is usually found in such works is omitted, while special stress and much space is devoted to statically indeterminant structures, and to problems concerning torsional stiffness and the stability of thin sheets under stress. Steel construction, as used in this country, is not dealt with directly, though many of the methods and formulæ given would apply to this material. But the metal with which it is contemplated that the aeroplane is going to be built with is duralumin, and it is expected that the wing will be constructed with a stressed skin and that the fuselage will be a metal monocoque.

In dealing with these matters the treatment is of great interest and the book is one which every designer who is likely to have to design such structures should read. Shear deflection, methods of joining parts by riveting or welding, flexible engine mounts, are all discussed, and special stress is laid on the problems of monocoque fuselages and concentrated loads, such as those produced by the landing chassis.

On the other hand, there are certain statements which are inexplicable. Why, for instance, should a characteristic of a determinate structure be given

as rigidity while a characteristic of an indeterminate structure be described as elastic? The one may be as elastic or as rigid as the other. Again, manganese molybdenum and nickel are described as "alloys," but this may be due to the American language not confining this word to combinations of metals. There are several other instances of this sort which suggest that similar terms do not mean the same thing on opposite sides of the Atlantic and the result is that the book is occasionally difficult to follow.

The 585th Lecture delivered before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS

An Ordinary General Meeting was held at the Royal Society of Arts, John Street, Adelphi, on Thursday, December 6th, 1934. In the chair: Lieut.-Colonel J. T. Moore-Brabazon, President of the Society.

The PRESIDENT: Opening the meeting, he referred to the Wilbur Wright Lecture which is given alternately by an Englishman and a foreigner, usually an American. The lecture is given at about the end of May near the date of the death of Wilbur Wright, and he was very pleased to say that a telegram had just been received from America to say that Mr. Douglas had accepted the honour of giving the next Wilbur Wright Lecture before the Society and that he would come over himself to deliver it.

Continuing, the President introduced Mr. R. P. Alston and called upon him to give his lecture on "Wing Flaps and Other Devices as Aids to Landing." No lecture, added the President, could be more opportune or more welcome than this at the present time. Mr. Alston was a product of that superb University, Cambridge, and he was also a disciple of Melville Jones. At the moment Mr. Alston was working at the Royal Aircraft Establishment and the lecture could not fail to be of the greatest possible interest and to arouse an interesting discussion.

The following paper was then read:—

WING FLAPS AND OTHER DEVICES AS AIDS TO LANDING

BY

R. P. ALSTON, B.A.

The Problem Before the Designer

It has long been recognised that landing and taking-off are the most hazardous periods of the average flight. In this respect an aeroplane is similar to a boat being launched or beached at high speed; the change from one medium of support to another is bound to involve possible damage especially if speeds are high.

So far as risk of mechanical damage, due to uneven aerodrome surface (or swell in the case of a seaplane), is concerned, the speed of landing should be the minimum practicable. Very low landing speeds have a possible disadvantage in that one may not have sufficient aerodynamic control to compete with gusts, etc., but there are few aeroplanes of to-day which have landing speeds so low that this objection can be raised.

The trend of design in recent years has been to increase aerodynamic efficiency by streamlining and to increase the wing loading. The first of these reduces the gliding angle and the second increases the stalling speed, the combined result being a large increase in the distance to rest after clearing a given obstacle (1). Faced with this problem, the aeroplane designer has to devise some form of air

brake combined with means of increasing the maximum lift coefficient. Curves of stalling speed plotted against maximum lift coefficient for various wing loadings are given in Fig. 1. With thin-winged biplanes a k_L max. of 0.55 was seldom exceeded, giving stalling speeds of 50 m.p.h. at 7lb./sq. ft. and 60 m.p.h. at 10lb./sq. ft.

There are at the present time two schools of thought with regard to the landing problem. In one the aim is merely to get back to the old war-time standard of a gliding angle of 10° and a stalling speed of 50 m.p.h., in the other the aims are far more advanced and an autogiro type of landing is considered. The requirements of the first school can be met by various devices which have

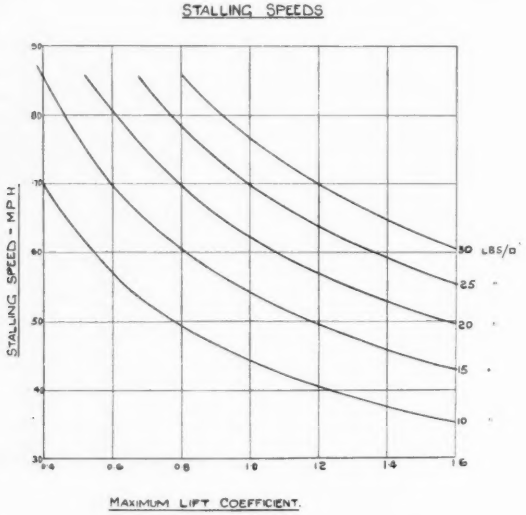


FIG. 1.

recently received considerable publicity and which it is the main object of this paper to discuss. After that we shall be in a better position to see what can be done to help the more advanced seekers of the perfect landing.

A comprehensive summary of existing wind tunnel data on high lift devices has been prepared by Mr. S. B. Gates (2), of the R.A.E., and I feel that one cannot do better than discuss these model and theoretical results in the light of what practical flying experience of them is available.

The MacRobertson race has given an opportunity to some people of seeing various forms of landing flap installed on really high-speed aeroplanes, and the pilots of these machines will probably agree that the flaps were a real necessity. The competitors in the two continental competitions this summer, the Europa Rundflug and the Coupe Deutsche de la Meurthe were obliged to use high lift devices in order to gain marks for the landing, take-off and slow flying sections. It is rather interesting to note that for the pure speed races, the MacRobertson and Coupe Deutsche, competitors favoured split flaps (no lift slots were to be seen), whereas all the Rundflug competitors used slots, usually in conjunction with flaps.

Nobody can fail to be impressed by the speed ranges attained in the Rundflug competition, but it must be remembered that the minimum speeds are measured by flying level over an 800-metre speed course with engine on, and are not the

same as stalling speeds with engine off. The values of lift coefficient obtained from the results of the actual competition are very high indeed, reaching in one case 1.9. These results were discussed in the aeronautical Press at the time and the favourable effect of slipstream was mentioned (3). An increase of engine power will stretch the speed range at both ends, consequently it is very hard to make strict comparisons between the minimum speeds of various aeroplanes with engine on. On the Heinkel now at R.A.E. the lift coefficient at minimum horizontal speed with engine on is 1.60, whereas the K_L max. with engine off is 1.08. Of the Rundflug competitors only one, the Polish PZL, had a split flap, the others had various forms of slotted flap, some of which moved back, giving an increased area (Fowler pattern). Further reference to some of these aircraft will be made later.

Means of Increasing Lift

There are two ways of increasing the maximum lift coefficient of a wing; one is to delay the stall by some means so that the normal lift curve is continued to a higher incidence, the other is to provide some means of increasing the lift at all incidences without altering the incidence for maximum lift. The former is usually effected by some device near the leading edge which acts upon the boundary layer in such a way as to prevent break-away of the flow; the Handley Page slot (4) and the " Mattioli " Diruptor (5) are examples of this general system. The slot is too well-known to need comment here; the Diruptor, however, is something rather novel and its action is not at all obvious. It consists of a thin rod about 1/100 chord in diameter supported near the nose of the wing about 1/30 chord above the upper surface. For the purpose of introducing small-scale turbulence into the boundary layer at high incidences the cross section of the rod is immaterial, but it should preferably be of oval section suitably set to give minimum drag at high speed. Systematic measurements of the effects of this device are being made in the compressed air tunnel at the N.P.L., which may, however, give erroneous results due to the turbulence already present in the tunnel. Full-scale tests of the device are believed to have been made by the inventor in Italy, but at present we are rather in the dark as to its effects.

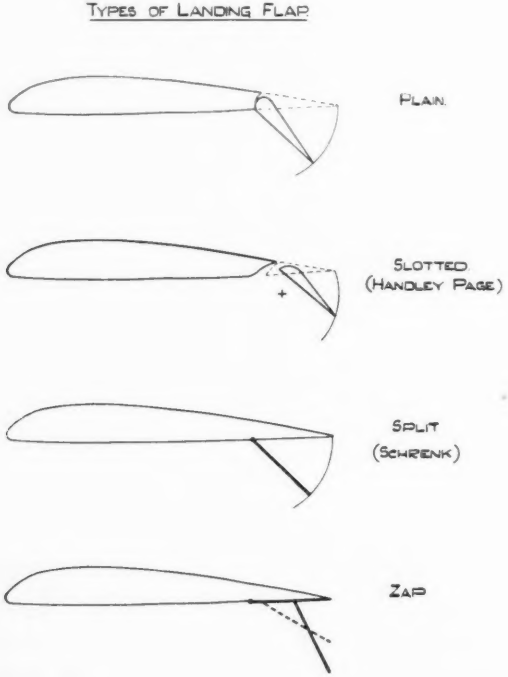
Flaps

In order to increase the lift of a wing at all incidences it is necessary to create an increased circulation. One way of doing this that has been the subject of much desultory experiment is to increase the camber. Variable camber wings have fallen into two classes, those in which the profile is kept smooth, and those in which a definite discontinuity has been present. Of the former, few have been practicable mechanically and nearly all have suffered from the disadvantage that the increased camber has been localised at a point about one-third of the chord back instead of being distributed further aft; this forward localisation produces an early stall. Of the latter type the plain trailing edge flap is the best example (6). Here the change in camber occurs at the rear spar, and being fairly well aft does not lead to an early stall.

The other way of stimulating circulation is to place an obstacle on the under surface of the wing near the trailing edge. The way in which this acts on the lift was investigated by Gruschwitz and Schrenk in Germany. They published a paper (7) in 1932 describing the results of experiments with flat plates projecting from the lower surface of a wing and they enounced a rational theory which covered all split flap devices for increasing lift.

According to their theory the function of the obstacle is partly to build up the pressure in front of it, but principally to create a wake, thereby reducing the pressure under the trailing edge. This pressure reduction at the trailing edge depresses the whole level of pressure of the upper surface and enables the boundary layer to sustain an increased pressure gradient, the stalling incidence

being unaltered. Pressure plotting over a model wing with and without a 10 per cent. split flap at 90° to the lower surface shows how the suction is increased over the whole upper surface. Schrenk deduced that the increase in k_L max. produced by any given obstacle would be proportional to the existing k_L max. without the obstacle. This last deduction has not been adequately checked; Schrenk intended it to include wings whose maximum lift coefficient was already high, due to a slot, but only one test of the addition of a split flap to an already slotted wing is available, and this gave a very poor increase due to the flap. Various model tests on different wings with similar flaps have given results which are more consistent when the absolute increase in k_L max., rather than the proportional increase, is taken as the criterion.



Schrenk's other principal deduction was that the greatest suction would occur two or three times the width of the obstacle behind it and that consequently the obstacle need not be very close to the trailing edge. This deduction has not been borne out by model tests; all the results so far show a progressive increase in k_L max. as the obstacle is moved back towards the trailing edge; though with very large flaps not normal to the chord k_L max. begins to drop off again in the extreme aft positions, see Fig. 4. In the extreme case where the front of the flap is moved right back to the trailing edge of the wing the whole arrangement then becomes equivalent to a wing of larger chord with a simple hinged flap.

Gruschwitz and Schrenk referred in their paper to similar work by Dr. Betz in Germany, to the Hiraki-Bane wing tested in Japan in 1930, and to a similar device tested for a firm in 1923. The Alfaro monoplane entered for the Guggenheim competition in 1929 had a form of split-flap variable area device, but it is unlikely that the wake creation principle was realised. A photograph of

the machine appeared in *Aviation* for October 19th, 1929, where it was stated that wind tunnel tests had shown the flap to give an increase of 87 per cent. in k_L max. on Clark Y. This is consistent with other tests on a 25 per cent. chord split flap pulled down 60° and moved back to the trailing edge. The Alfaro appears to be the first machine to be flown successfully with such a flap. A patent for a split trailing edge flap was granted to Orville Wright in 1921, and it would be interesting to know why it was neglected for the next ten years or so. Schrenk's name has become attached to split flaps in a rather vague kind of way and it is not at all obvious what the definition of a Schrenk flap is, but I think it may be taken to include any flap which leaves the upper surface of the wing intact and which is either hinged about its front edge or is lowered and raised through a slit in the wing. One of the first (late 1932) firms in U.S.A. to use a hinged split flap was the Northrop Corporation, whose name consequently became associated with their version, namely, a 20 per cent. chord flap hinged at its forward edge through a maximum of 50°.

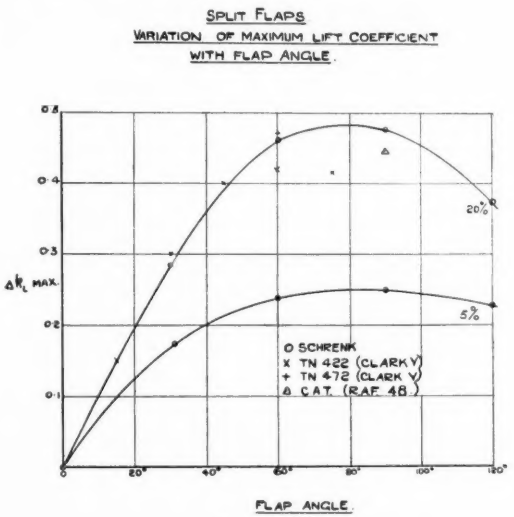


FIG. 2.

The Zap flap, named after its inventor Zaparka, is a split flap whose front edge is moved back as the flap opens in such a way that the trailing edge of the flap is immediately below the trailing edge of the wing (8).

Finally, there is the slotted flap as favoured by Messrs. Handley Page. Here the rear portion of the wing is hinged bodily in such a way as to leave a well-shaped slot between the wing and the nose of the flap in the open position. An extension of this principle is found in the Fowler wing (9) in which the flap moves aft as well, giving an increased area effect. The slotted flap operates, like the split flap, by creating a suction at the trailing edge of the main wing, but the suction is derived from the nose of the flap.

Wind Tunnel Tests

Following the above review of the principles of operation governing various high lift devices we are in a better position to examine the available wind tunnel data. The validity of wind tunnel tests at low Reynolds numbers has always

been open to doubt in the matter of maximum lift coefficients, and even compressed air tunnels are not entirely above suspicion on account of turbulence. There is, however, a saving grace where split flaps are concerned, which is that various different tunnels agree in giving unaltered stalling incidence when the flap is in operation. The change in k_L max. due to the flap is therefore probably not much in error. Fig. 2 shows the effect of flap angle on the change in maximum lift coefficient for a split trailing edge flap running across the whole span. The curves are taken from Gruschwitz and Schrenk's experiments for a 20 and 5 per cent. chord flap; the other points are from American experiments on a 20 per cent. flap; the increase in drag coefficient at $k_L=0.5$ is plotted in Fig. 3. It will be noticed that no advantage in lift is gained by having a larger flap angle than 60°, though the drag increase continues to rise with flap angle. The effective drag increase obtainable with a flap is of course

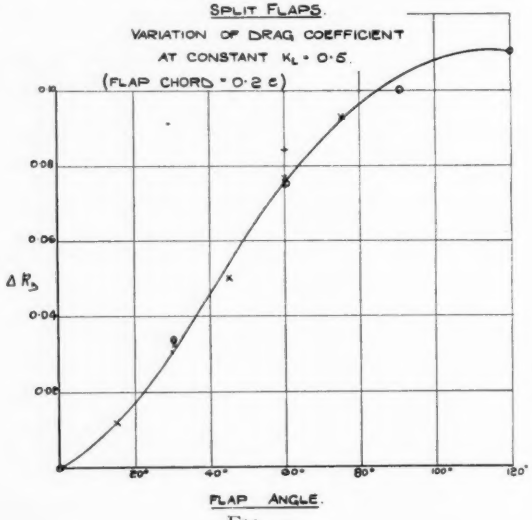


FIG. 3.

more than that shown in Fig. 3 since there will be extra induced drag due to operating at a higher k_L.

The effect of flap location is shown in Fig. 4, whence it appears that the further back the flap is, the greater the maximum lift coefficient. The effect on drag is negligible. Unless some mechanism such as the Zap is utilised to slide back the leading edge of the flap, the furthest aft location is limited by the flap chord in the closed position. The effect of varying chord for total span split flaps deflected 60° is shown in Fig. 5, where the loss of lift due to forward location is seen to exceed the gain due to size when the flap chord exceeds about 30 per cent. of the wing chord. Drag continues to rise, however, as would be expected.

The effect of variation of the flap span has been investigated in detail for a 20 per cent. chord flap at 60° deflection, cut away at the tips and centre in turn (11). The results are as one might expect; removal of the flap from the centre causes a rapid drop in lift and so disturbs the span distribution that the induced drag is increased; removal of flap from the tips does not decrease the maximum lift so seriously. It is a pity that these experiments were not associated with any measurements of tail flow since there is a certain amount of full-scale evidence

that in order to maintain sufficient downwash at the tail on low-wing monoplanes it is essential to run the flap right across the centre of the wing span. Comparison of the lift curves at equal values of maximum lift shows a less sudden drop at the stall when the centre is cut away than when the tips are cut away. One of the first machines to be fitted with a split flap was the Northrop " Sky Chief," on which the flaps ran from the end of the wing-body fillet to the wing tip. " Park bench " ailerons (which will be discussed later) were fitted. It was stated by Mr. Northrop that the stall on this aeroplane was not violent, a fact which may be attributable to the non-flapped centre portion of the wing.

Before going on to discuss the various forms of special ailerons that are required if flaps are run right out to the tips it may be as well to determine what can be done with partial span flaps. It has already been shown that a flap chord of 20 per cent. and a deflection of 60° need not be exceeded from a lift point of

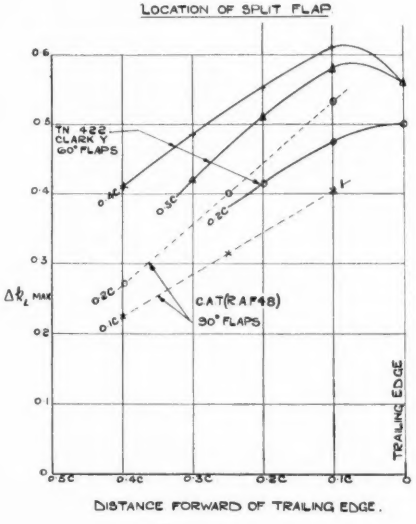


FIG. 4.

view. On a typical tapered wing monoplane, the ailerons need not exceed 40 per cent. of the span so that the central 60 per cent. is available for a flap which, on a rectangular wing, would give an increase of 0.325 in k_L max. Owing to the concentration of load at the centre of a tapered wing this figure may be increased to 0.35. For a wing loading of 16lb. per square foot and a k_L max. of 0.7 (no flap) the stalling speed is 67 m.p.h., which would be reduced to 54.5 m.p.h. by the flap. The increase in gliding angle at 20 per cent. above stalling speed would be 6°, which would be adequate to bring even a very clean aeroplane above the war-time standard of 10°. Estimates of the effect of the flap on the Douglas D.C.2 suggest a reduction of stalling speed from 68 to 59 m.p.h. and increase in gliding angle of 3°. The minimum distance to come to rest after clearing a 100ft. obstacle is calculated to be reduced from 2,000 to 1,350ft. This calculation is based on the assumption that the approach is made at the minimum speed from which complete flattening out is possible in each case and that the coefficient of friction on the ground is 0.3 with brakes. It should be noticed that any excess of speed on the approach will result in a greater increase of run for the unflapped aeroplane. It appears, therefore, that in order

to make a clean, heavily loaded aeroplane reasonably easy to land it should not be necessary to have full-span flaps. This conclusion would appear to have been justified in practice since no full-span flap is believed to be in use commercially now except on the Pander Postjagger.

Special Ailerons for Use with Full-span Flaps

If a split trailing edge flap is run right out to the wing tip some unconventional form of aileron must be employed. One method is to use ailerons in the normal position but so arranged that they move upwards only, through a large angle. American model tests show that the angle has to be about 70° to give rolling moments comparable with those of conventional ailerons. Ailerons of this pattern have been tried in flight on the Fairchild F.22 monoplane with a

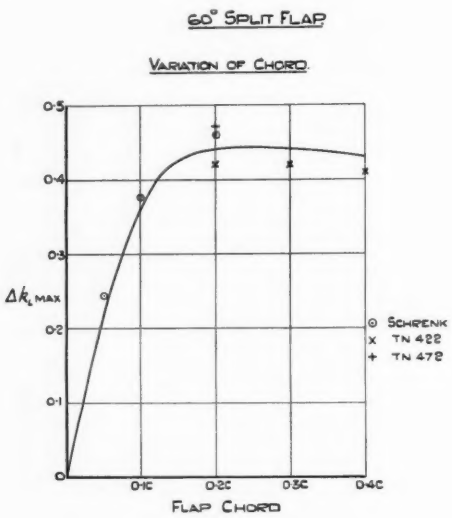


Fig. 5.

full-span split flap and are believed to have been abandoned on account of excessive hinge moments. An alternative developed by the N.A.C.A. is a retractable curved plate aileron which need involve no aerodynamic hinge moment; these ailerons have been used successfully on the F.22, but they must involve considerable extra weight.

Leading edge spoilers or interceptors appear very promising from model tests, but when tested in flight by the N.A.C.A. they gave an initial reversed control equivalent to a half second lag.

The only remaining solution is an auxiliary aileron mounted above the trailing edge of the wing, a type christened " Park bench " in the U.S.A. According to the Zap Corporation, who use this type in conjunction with a full-span Zap flap, the exact location of the aileron and its zero setting is very critical. A feature of this type of aileron is that its rolling moment coefficient is increased when the lift flap is down so that adequate control should be preserved at low speeds. Possible objections to this type are its extra weight, drag at high speeds, and likelihood of causing torsional distortion of the wing owing to its far back location, but full-scale tests in this country will shortly settle these points.

Pitching Moments Due to Split Flaps

The effect on longitudinal trim when a flap is pulled down is rather complex since it involves three factors, the backward shift of the wing centre of pressure, the lateral shift of the $k_L \sim a$ curve, and a change in downwash over the tail. There is also the possibility of the turbulent wake causing a drop in tail efficiency. The simplest condition to consider is that of unaltered speed when the flap is down, *i.e.*, k_L is kept constant, which means that the incidence is reduced. Consequently there is a nose up pitching moment produced by the reduced incidence of the tail. At constant k_L the downwash at the tail should be practically un-

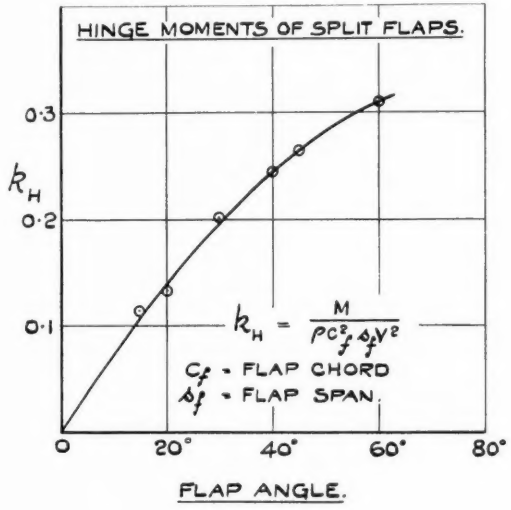


FIG. 6.

altered for a full-span flap. From model tests on split flaps of chord varying from 15 to 30 per cent., the wing pitching moment has been plotted against incidence for various flap settings at constant k_L (0.5). dk_m/da from these points has a value of 0.009 per degree. An average tail plane designed to give adequate longitudinal stability may have a value of 0.007 for dk_m/da, so that there is a net nose down pitching moment of 0.002 per degree change of incidence at constant k_L. For full flap angles the change in incidence is about 12°, giving a net pitching moment coefficient of -0.024 only. Some tests made by the Zap Corporation on models of the XOJ-1 biplane and Parnall Parasol monoplane even show resulting nose up moments at a given k_L and practically no change in moment at maximum lift. In these tests it is hard to see where the additional nose up moment comes from.

Failure to carry the lift right across the centre of the wing, either due to interruption of the flap or to bad body-wing interference, will reduce the downwash at the tail for a given lift coefficient and almost certainly make it impossible to attain stalling incidence if that incidence is only just attainable with no flap. In order to ensure that stalling incidence is just attainable with and without flap it may be necessary to gear together the flap and tail plane adjustment or alternatively to arrange that the gearing between elevator and stick is increased as the flap is pulled down. The former system was adopted in the Fieseler 97 in the Rundflug competition. This machine has a Fowler flap involving a very big C.P. movement and its tail plane is set down 16° by full flap movement.

In spite of this its minimum speed figure (engine on) only gives a k_L of 1.57, so it is quite likely that there was insufficient longitudinal control to trim the aeroplane to the incidence for maximum lift, though engine power and lateral control may also have been inadequate.

The sharp drop in lift at the stall that has been noticed in model and full-scale wind tunnel tests of split flaps has given rise to some anxiety on the score of a possible large loss of height in recovery from a stall, combined with acute lateral instability. Mr. Relf has suggested that on this account the longitudinal control should be limited to prevent the attainment of stalling incidence, but full-scale evidence on this point is needed.

Operating Forces for Split Flaps

Data on the hinge moment and centre of pressure of a split flap are a little scarce (13). Curves of hinge moment for split flaps are shown in Fig. 6. For such flaps the hinge moment is nearly proportional to the angle of deflection. The rapid increase of hinge moment with chord shows that flaps should be kept as long and narrow as possible for a given area, a requirement in conflict with the avoidance of aileron troubles. A calculation based on these hinge moment figures shows that the moment required to hold down the flaps of a machine like the Douglas D.C.2 is about 700lb. ft. at 75 m.p.h. This demands the use of auxiliary operating gear which may be electric or hydraulic but is bound to be fairly slow acting. A criticism of the flap installation on the Northrop " Sky Chief " was that 45 turns of a crank handle were required to get the flaps down; this manual system has been replaced on later Northrop machines (with smaller flaps) by a hydraulic gear, and it appears that manual operation of a plain split flap of useful size is impracticable on any but light aeroplanes.

It is in connection with operating force that the Zap arrangement is of principal interest; by hingeing the flap to a link about one-third of its chord back and allowing the nose of the flap to slide back, the flap may be nearly in balance at high angles. The position of the flap C.P. is open to some doubt; N.A.C.A. tests on plain split flaps show that, at the operating incidences, the C.P. moves back from 30 per cent. of the flap chord at 15° deflection to about 40 per cent. at full deflection, whereas some tests by the Zap Corporation show the C.P. to move forward from 0.5 to 0.3 of the flap chord as the angle increases from 20° to 40°. On the latter basis the flap is self-opening at high angles. For a simple hinged trailing edge flap there is a theoretical relation between hinge moment, flap angle and lift coefficient due to H. Glauert; this relation has been checked very closely by pressure plotting on a R.A.F. 30 flapped wing and by direct measurement on a R.A.F. 31 model. The results show a straight line law for k_H against flap angle at a given k_L, and the value of k_H at 45° flap angle is identical with that for the split flap given in Fig. 6.

The Slotted Flap

The principle of operation of this flap has already been referred to, and it would be expected that the drag would be comparatively low. Wind tunnel tests on a Handley Page slotted flap of 20 per cent. chord ratio show an increase in k_L max. of 0.445 at 40° deflection and an increase of only 0.018 in k_D at $k_L=0.5$. With the slot blocked up Δk_L max. $=0.32$, $\Delta k_D=0.017$ at $k_L=0.5$. Some other tests on slotted flaps (14) show them to be the type having the least increase in drag for a given increase in maximum lift coefficient.

With regard to hinge moments, no figures are available, but it appears possible to locate the hinge in such a position that the flap is well balanced and has a suitable slot opening. There is no advantage in having the flap angle greater than 40°, so that the range of movement is less than that required from a split flap to give the same increase in maximum lift coefficient.

Air Brakes

All the devices discussed above have been regarded principally from their effect on maximum lift, and the drag has been left to look after itself. If k_L max. is assumed to be increased by a flap from 0.6 to 1.0 then k_L on the glide will be increased from 0.45 (at 15 per cent. above the old stalling speed) to 0.7 (at 20 per cent. above the new stalling speed). For an effective aspect ratio of 6 this means that the induced drag coefficient is increased from 0.021 to 0.051. The parasitic drag may be increased any amount from 0.016 for a slotted flap to 0.089 for a 90° split flap, so that the total increase in gliding angle, given by $\tan^{-1} \Delta k_D/k_L$ ranges from 2.8° to 11.5°. This can be said to cover any normal requirement, ranging from the case of low drag increase where improvement in take-off is required to quite a high drag increase where short landings are required.

There are other means of increasing drag alone without altering the wing lift characteristics, but they are not very effective. A retractable undercarriage which is badly faired when down, rotatable strut fairings, flaps projecting from the fuselage, and such devices are only capable of producing quite small drag increases. A variable pitch airscrew windmilling at very low pitch has been calculated to give quite a good braking effect, but the tail controls might be impaired by a " negative " slipstream. A device which acts as a pure air brake and has been tried successfully in flight is the D.V.L. gliding angle control (15). This consists, essentially, of two small surfaces, one on the upper surface of each wing, which are parallel to the plane of symmetry when out of action and can be rotated about a vertical axis. When turned normal to the direction of flight they break up the span distribution of loading and so increase the induced drag of the wing appreciably though their own parasitic drag is small. Flight tests on a German low-wing monoplane showed an increase of 5° in minimum gliding angle with this device without appreciable increase in stalling speed.

Weight of Flap Installation

There is very little evidence in this respect. Experimental flap installations on the Parnall Parasol monoplanes give figures of 250lbs. for the complete outfit, including controls, of a 28 per cent. chord Zap flap of full span, except for a small centre section cut away, and 65lbs. (estimated) for a 10 per cent. chord full span curved retractable flap and associated controls. The former has already been fitted to a R.A.F. 28 section wing and involves " Park bench " ailerons, the latter is shortly to be fitted to a R.A.F. 48 section wing; both wing areas are 294 sq. ft. The Zap installation weighs 8 per cent of the all-up weight of the aeroplane and, from Fig. 4, should give a 75 per cent. increase in K_L max. The retractable flap installation weighs 2 per cent. of the all-up weight and, from Fig. 4, should give a 40 per cent. increase in K_L max. The weight figures in both these cases are for experimental installations on existing wings and are probably unduly heavy on that account, but even so a device which itself weighs only a tenth of the increase in lift that it gives may be regarded as good.

Performance

Speeds of operation of commercial and military aircraft are steadily rising owing to competition, and in the U.S.A. there is hardly a passenger transport aeroplane not fitted with some form of flap and some of their military machines are now fitted with slots and flaps.

Where high top speed is essential, landing devices will be used, not to reduce the landing speed, but to keep it the same, increase the wing loading and so obtain a higher top speed. Calculations show that even with a split flap used for landing only (on account of its high drag) the performance of a typical two-seater fighter could be increased by at least 10 m.p.h. on top speed and a variable

amount on climb according to how the aspect ratio is changed. A maximum lift coefficient of 1.1 which is really usable at a normal stalling angle now appears to be possible; this permits a wing loading of 20lbs. per square foot for a stalling speed of 60 m.p.h., and 30lbs. per square foot at 74 m.p.h., which is not an impossible speed for a large flying boat.

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15. The D.V.L. Gliding Angle Control. By W. Hübner and W. Pleines. Z.F.M., Aug. 12th, 1932.

Discussion

Mr. H. E. Wimperis (Fellow and Vice-President): In deciding whether the plain flap, or the slotted flap, or the split flap were preferred, the first question to be asked was what was really wanted; for unless they made up their minds what condition they were trying to fulfil it would be found very difficult to choose among the wealth of alternatives that were available. Appreciating this he had prevailed on Mr. Gates, a member of the Air Ministry Research staff, to write a report arguing the case and giving conclusions as to what, he thought, would be the ideal at which to aim. This report, which would be published, reached the conclusion that one should aim at a 50 per cent. increase in lift, with a gliding angle of 1 in 6 at a speed of 1.2 times the stalling speed. He accepted this requirement as a reasonable statement of the case, and bearing this in mind he had asked the question how far the four forms of landing flap shown would meet it. The three newer types shown were the Handley Page slotted, the Schrenk split and the Zap; any one of these three in the right combination of its elements could fulfil the ideal requirement and therefore it was simply a matter of the designer to choose which of these three would fit his other requirements best in respect of cost, additional weight and the kind of aeroplane he was proposing to build.

At the end of the paper the author said:—"Calculations show that even with a split flap used for landing only the performance of a typical two-seater fighter could be increased by at least ten m.p.h. on top speed. . . .," and bearing in mind that most of this knowledge had been before them for at least three years, how was it that extra ten m.p.h. had not been obtained?

Air Commodore J. A. Chamier: Three lantern slides were shown to illustrate what he wished to say on the subject.

The first was a picture of a Clark Y wing indicating what was happening, and the points he wished to draw special attention to were the small thickness of the affected layer of air represented by the streaky lines above the wing, the angle at which they came down and the angle at which they left the trailing edge of the wing, this being nearly horizontal.

The second represented a wing with a split flap at an angle of incidence less than that shown in the previous slide and it would be noticed at what an enormous distance—up to the top right hand corner of the picture—the streaky lines could be seen. Also in the centre of the wing they were right up to the top of the picture. The angle at which they came sweeping down behind the wing, to an amateur like himself, was most illuminating. They were rushing down to get into the vortex which the author had described.

Air Commodore Chamier spoke of some of his practical experiences in this connection. He had flown a flapped machine in America for a fair number of hours and that experience might be of some assistance in trying to solve the problem that had been put before the meeting.

The third slide showed the machine in question, which was a high wing monoplane, and it was an extremely unpleasant machine to fly before flaps were fitted. In the picture the flaps were down at 60 deg. and the ailerons were at extreme angles and they did not look so terrible (although the picture was doubtless taken to show them at their best). There was nothing tricky about this machine. The wing section was Clark Y and the undercarriage had six inches travel. He had flown it for a number of hours, some of them in very nasty weather, and the first thing that impressed him was the ease of operation of the trailing edge flap. The machine was, it was true, a slow machine compared with the fast ones on which flaps were being fitted to-day, but there was no effort involved in getting four degrees flap angle per turn of the control wheel, and four degrees made a very big difference when using flaps.

It was most important that there should be balance on the flaps both from the structural point of view and the handling point of view, because it might be necessary to use them in the case of a heavily loaded machine in which the engine failed immediately after the take-off with the flap housed. Similarly, it was necessary in judging the approach on landing to come in on the flaps only, adjusting the gliding angle to reach the spot that was required.

It was also important that the flaps should be capable of being brought into operation rapidly, because in the case of a snap take-off, so to speak, it would be necessary to house the flaps to reduce the drag and then bring them into action quickly and jump off the ground. In the United States he understood they had been found very useful for carrier work and that they had been very successful also for seaplanes because they enabled the pilot to jump off before hitting a wave. On the other hand, they had been found useful in enabling the seaplane pilot to idle in the air until he could come down safely.

On the particular machine which he had flown—the high wing monoplane—he had been able to sit with his hands off the stick altogether and wind the flaps down to 60 deg. without anything more than a slight change of trim, which was not very noticeable. The change was in the form of a diving moment, and it was the less noticeable because the speed did not pick up owing to the high drag.

This machine was also rather surprising in the retention of control at very low speeds. With the flaps housed, the ailerons went out of action at about 42 miles an hour indicated air speed. He did not know what would have been the case with ordinary ailerons, but these were the park bench type. When the flap was down terrifying indicated air speeds were obtained, something like 15 to 18 miles per hour with the needle nearly against the stop. Not having a swivelling Peto head this meant that the speeds were something like 30 miles an hour, but they were sufficiently terrifying. The Americans were optimistic people

and offered any machine to any stranger, even to bad pilots like himself. He did not suggest that the ailerons were nice and he knew that one of our test pilots regarded them as abominable, but they worked, and there was complete control laterally, longitudinally and directionally.

Nothing had been said by the speaker about the marked stall with these devices, but information on this aspect had been published and theoretically there ought to be a very steep drop of the lift coefficient beyond the stall on these machines, and they ought to spin. As a matter of fact there was a statoscope on the American machine, and he had rocked it to and fro with the engine off, through various rates of descent from 1,000ft. per minute, through 600, and back to the 1,000 again. He had pulled the stick back at 600ft. a minute, but there was no trouble and the machine was perfectly safe.

A quicker take-off in space was noticeable, although not in time. The machine certainly got off quickly and the angle of climb appeared to be a little better than normal, although, of course, owing to the drag, the rate of climb was deplorable, but that did not matter very much. One took off and ran over the ground very slowly until the obstacle was reached and then turned inside it and kept running round the confines of the aerodrome like a mad butterfly until one climbed high enough to go over the hedge.

The rate of climbing with this particular machine increased with about 5 deg. of flap. It might be possible eventually to have a symmetrical section speed wing and use a small amount of flap for climbing purposes and a large amount of flap for landing purposes; that was a line of thought which might be followed up.

There were a number of ways of landing this machine, and most of them felt very strange. If one landed in the ordinary way, unless there was a great excess of speed it seemed very clear that there must be a very steep angle of descent and the ground came up towards one very fast indeed. If the stick were pulled back, probably over the top of the lift curve, the ground came up faster still. He obtained permission from the American authorities to land the machine by the statoscope at the top of the lift curve and sat still, as the author of the paper had described, and it was very successful in spite of having only six inches of travel on the undercarriage. He hit the ground fairly hard. That was the worst that happened except that in a wind of 30 miles an hour by the aerodrome anemometer the tail wheel reversed as he touched the floor.

The PRESIDENT: Could anybody present speak about the Mattioli diruptor?

Mr. MILES: He had carried out a few tests on the Mattioli diruptor, but the details available were not sufficient for an exhaustive test. The *Aeroplane* of August 29th, 1934, published a photograph and a short description, and there was also an English patent specification in the name of the inventor, Dr. Mattioli, of Padua University. From these he had made an attempt to try out the effect of a round section rod placed near the leading edge chord and moved nearer to or farther from the wing surface. The test was necessarily rough, but he had wanted to get some idea of what effect could be expected. With the best obtainable results he had come to the following conclusions:—

1. That the maximum k_L for the machine could be definitely increased.

2. That the tube did not combine well with flaps and that when placed in front of the ailerons it decreased their effectiveness.

3. The best position tried was well down on the nose of the aerofoil and about 1/100 chord above the surface.

4. Long tapes fastened to the wing showed that the diruptor delayed the stall, but that when the tube was removed from the outer part of the wing the inner part with tube still in front stalled first. The tapes always flew inwards and forwards during the stall and never outwards. When in front of the aileron, however, a small downward movement of the aileron broke up the flow at once and it seemed to require rather more than the usual period to re-establish itself.

In fact, he found that with the diruptor in front of the aileron the tendency was to make it behave badly. He hoped, however, to have another try sometime because of the definitely increased lift coefficient he had found on the first occasion.

Referring to flaps, Mr. Miles said he had been concerned in the carrying out of a good deal of actual flying experiment with various arrangements of flaps and as a result felt justified in confirming certain points raised by Mr. Alston. There seemed little doubt that the flap was more effective as a lift increaser when fixed 60 per cent. or more behind the leading edge. It was found that the best results were obtained with a 10 per cent. flap hinged at 90 per cent. of the chord and extending unbroken from the inner end of one aileron to the inner end of the other. With this arrangement normal controls were used without modification. In fact, some improvement could be noted at and beyond the stall in both lateral control and stability. The improvement was probably due to the fact that the inner flapped portion of the wing reaches its angle of maximum lift before the outer unflapped portion so that the ailerons were working on a part of the wing which remained unstalled after the aeroplane as a whole had stalled. There would also be a sort of equivalent wash-out tending towards lateral stability. The recovery from the complete stall, contrary to wind tunnel indication, was very quick and definite and the general feel of the controls was very good. It was difficult to stall the machine viciously enough to make the nose drop below the horizon before recovery.

It had been remarked by Mr. Alston that the down flow over the tail might be affected by flaps. That this was so could be borne out by his own experience. When the tests in question were first carried out the flaps were placed, as usual, on either wing. The pitching moment was considerable and he had thought it would be necessary to fit a powerful tail plane adjustable over a large range of incidence to cope with it. However, further tests with the flap continued unbroken right across the fuselage showed not only was the adjustable tail plane unnecessary, but that no alteration to trim was required at all. Apparently what happened was that with the separate flaps the accentuated downwash was carried outwards and missed the tail plane altogether. This might be due to the existence of a region of lower pressure over the flapped portion of the wing than obtained over its centre. The behaviour of long tapes fastened to the trailing edge of the wing bore out this theory. Before the centre part of the flap was fitted they tended to diverge from the fuselage, but after the flap was made continuous a marked convergence of the tapes took place and the tail plane could be clearly seen to be working in a much increased downwash angle when the flaps were put down.

With the engine opened up just enough to maintain height, they were getting an estimated overall k_L of about 1.07. Making an empirical allowance for that component of thrust assisting lift, he would say that with the engine off the overall k_L would be 0.9. This showed a smaller difference than was indicated by Mr. Alston, but he presumed the machines mentioned by Mr. Alston had the engines running hard at a considerable angle, whereas in his own case the throttle was closed as far as possible, still maintaining the machine in level flight.

Speaking of the load on flaps, Mr. Miles said that even on a small machine the load on the flap was considerable and in order to obtain quick manual control some method of balance was required. The weight of the complete flap installation as fitted to the Miles " Hawk " was about 30lbs.

Dr. G. V. LACHMANN (Fellow): With reference to the Mattioli wing he was surprised to hear that Mr. Miles had observed an increase of maximum lift because this was actually not claimed by the inventor. He had been in contact with Mr. Mattioli, who had sent him all his publications. What Mr. Mattioli really claimed was the introduction of a kind of secondary turbulence into the boundary layer, and the effect was to cut off the peak of the lift curve and to produce a flat-topped lift curve. The purpose of this device was therefore to

prevent dropping of a wing at large angles of incidence, but not to increase the maximum lift, which was in fact reduced. If Mr. Miles had found an increase of maximum lift on his machine, he imagined that this was due to the fact that the diruptor improved the lateral stability near the stall and made it possible to utilise the lift of the wing to a fuller extent than with the normal wing without the diruptor.

Mention had been made by the author of the split flap that it had given unsatisfactory results when combined with slots. They had tried a model of this kind in the Handley Page wind tunnel and had obtained very satisfactory results; the effect of the flap was actually better with slots than without.

There was one very important point which the author had not stressed, namely, the fitting of flaps to tapered wings. Available information referred exclusively to rectangular wings. The tapered wing differed materially from the rectangular wing in regard to distribution of k_L across the span. When one calculated the k_L distribution across the span, according to the methods developed by Glauert and Lotz, one found that the distribution of k_L showed a definite increase towards the tips which indicated that the wing stalled first at the tips and not at the centre like a rectangular wing. When one now calculated the distribution for a tapered wing fitted with a flapped centre portion, one found a strong concentration of lift and induced velocity towards the centre of the wing. The outer ends of the wing having practically no induced velocity and at the point where the flap ends, the downwash becomes reversed in sign so that the local effect of incidence is high which leads to premature stalling.

It was therefore impossible to obtain the maximum lift out of the flapped portion because the outer wings could not produce sufficient lift in order to continue the theoretical k_L distribution curve. For the flapped part of the wing the maximum lift coefficient might be of the order of 1.1 and for the normal wing section at the outer part of the wing 0.65. He believed that the best way to bridge the gap between the unflapped portion and the flapped part of the wing was to fit wing tip slots to the unflapped part, because it not only gave sufficient lift to continue the k_L distribution curve, but also a certain margin for damping in roll. It also permitted the use of the orthodox well tried out aileron for lateral control instead of new fangled park bench ailerons, etc., which become necessary with a continuous flap.

A check on this phenomenon had been obtained in the Handley Page wind tunnel when exploring the region immediately behind the trailing edge of a tapered aerofoil at high angles of incidence with slotted centre flap depressed. By means of a silk streamer it had been observed that burbling commenced just outboard of the flap exactly as the theoretical analysis predicted. It was also known to him that on certain continental aircraft, having tapered wings and fitted with centre flaps, accidents had occurred due to a sudden viscous dropping of a wing. At the last Aeronautical Salon in Paris, a certain type of aircraft was shown fitted with very effective flaps and also with wing tip slots. These slots, however, were clearly an afterthought as it obviously had been impossible to obtain the maximum effect from the flaps without them.

The information in the paper in regard to slotted flaps was rather meagre, although it was a home produced article and not made in U.S.A. The slotted flap gave about the same maximum lift coefficient as the split flap of equal chord and there was also a considerable increase in drag when pulling the flaps beyond 50 or 60° without reduction of lift. The great advantage of the slotted flap compared with a split flap, however, was in his opinion that the profile drag of the slotted flap was considerably less at 20 to 30° flap angle which resulted in improving take-off. It was a known fact that the split flap did not help in the take-off because the lift of a split flap was invariably bound up with increase of drag. The slotted flap, on the other hand, only gave a slight increase of profile drag, but still gave a very considerable lift increase at a flap setting of 25 to 30°,

because here lift increase was not a function of drag. According to his investigations the slotted flap reduced the take-off run by about 25 per cent.

Reference had been made by the lecturer to reduced hinge moments obtainable with slotted flaps and he also regarded that as a great advantage.

Continuing, Dr. Lachmann said he thought the author was too pessimistic with regard to the landing angle of a fully slotted and flapped aircraft when performing a so-called " autogiro " landing. The author had mentioned that the aircraft would have to touch the ground at an angle of 30°; actually the maximum angle required to obtain maximum lift for a slotted and flapped aircraft was only of the order of 22 to 25°, and as the gliding path was inclined at about 12 to 13°, the attitude of the aircraft relatively to the horizon was only about 10 to 12°, which was a normal ground angle.

Some members of the audience had probably seen the film which Mr. McPherson had demonstrated at the Royal Aero Club a few days previously in which were shown some excellent landings performed at Warsaw during the technical trials of the last Rundflug. He also did not agree with the author that the problem of controllability at low speed was unsolved because he considered that interceptors gave all the lateral control which was required, and as far as longitudinal control was concerned, it was not known to him that it offered any particular difficulty, especially as there was always the throttle as a powerful assister as long as the engine was running. He saw no reason why the throttle should not be used as an additional control for landing. It was an old fashioned idea not to do this, but new devices required a new technique, and it was obvious that as long as the engine was running the throttle was the best way of controlling rate of descent.

Professor G. T. R. Hill (Fellow): As a matter of historical accuracy he thought it right to say that the flapped wing dated back to well before the war. He remembered some wind tunnel tests carried out by the R.A.F. on R.A.E. 9 section and there were some present that evening who could confirm that these tests were carried out over 20 years ago. During the war he himself had flown one machine known as the S.E.4A. which had flaps which extended all the way along both wings, and which were also used as ailerons. When all the flaps were pulled down a slower landing speed was actually achieved, but at the lower speeds the lateral control was definitely poor, and little, if any, advantage was gained by use of the flaps.

Coming to more recent times, Professor Hill recalled that in the paper which he had read before the Society in 1926 he was able to describe an air brake which had been tried out successfully in the air; this brake was fitted to the Mark I Pterodactyl, and was formed by operating simultaneously the two rudders below the wings; by turning these two rudders outwards it was possible to reduce the gliding angle from something of the order of 1 in 10 to about 1 in 6. He did not know how the magic figure of 1 in 6 arose, but he believed it was roughly the gliding angle of the Sopwith Camel, which was supposed to be one of the machines which could easily be landed in a small field. Personally he felt that 1 in 6 was a very fair figure to aim at, and of course this was another, and possibly more commonly visualised, way of expressing the figure of 10° mentioned by the lecturer.

In conclusion, Professor Hill said that in January, 1930, a patent was taken out by the Westland Aircraft Works and himself for a flap which, so far as he could see, was identical with the Zap flap. It rather seemed that he would have to talk to Zap about that!

Mr. H. Brewer: There is a definite tendency among scientists to give credit for invention to the continent. If a device was given a certain name—Schrenk, for instance—it was immediately talked about, tested scientifically and fostered by research workers. In the first place, however, the flap was a British invention and had been entirely British since its inception in 1916. Since then, some

1,600 aircraft had been in use in the R.A.F., incorporating flap gear, and even to-day, as had recently been stated at a meeting of the Society, a famous flying boat designer, Mr. Sikorsky, paid tribute to this British device whereby at 28lbs./sq. ft. loading he was able to obtain 40 per cent. increase of lift, and decrease his take-off time by 40 per cent.

Until the last two or three years all flap work had definitely been neglected by the scientific side as it savoured too much of an *ad hoc* experiment. It was actually too simple in fact and too complicated in theory, and that was the answer to the lecturer's query when he mentioned the neglect of Wright's patent in 1921. The blame was on scientific research workers to whom they were supposed to look for guidance on these matters. He understood that the American aeronautical engineer holds this view very strongly and also that Schrenk's name should in no way be associated with the split flap except that in 1932—11 years after the invention—he propounded a theory covering its operation. He honestly believed that they would make quicker progress on devices such as these if the research worker did not always wait for the theory before going ahead with development in the tunnel and full scale.

With regard to the Douglas machine, this was certainly getting its share of publicity, but as the matter had been mentioned by the lecturer he would like to correct certain data from first-hand information which he had received. The flight concerned was made in the Douglas machine which gained second place in the MacRobertson race and was during one of the last test flights before it was handed over to the K.L.M. That machine was actually landed in a distance of 250 yards after clearing an obstacle definitely over 100 feet. This, it must be admitted, was on a prepared runway, but it was about half the figure of 1,350 feet given in the paper. The best figures which could be obtained on this machine were 500 feet after clearing a 100 feet obstacle. The flaps down gave 35 per cent. increase of lift with the phenomenal increase of drag of 300 per cent. Naturally they were used for landing only, giving an excellent angle of approach without desperate inclination of the passengers' compartment. As regards operation, the time taken was from 8 to 12 seconds, which could not be called slow-acting.

Finally, with regard to the hoped for improvement in speed due to the use of flaps, given as 10 miles per hour for a two-seater fighter, Mr. Brewer said it must be remembered that specifications call for an equally severe take-off condition for which the wing area has usually to be designed.

Flight Lieut. G. H. STAINFORTH: His reason for speaking was that they had had some flying experience at Farnborough with two or three machines fitted with different types of flaps. Two were tapered low wing monoplanes, one with flaps which did not pass under the fuselage, the other with flaps extending across underneath. Another was the R.A.E. Parnall Parasol monoplane.

From the pilots' point of view they had been very favourably impressed with split flaps, which reduced stalling speed by about 15-20 per cent.; gave a steeper glide, making it easier to land on a given point; the nose was further down, giving a better view; " float " was greatly reduced, and it was not necessary to keep the approach speed within very small limits in order to give minimum float, while having enough speed to flatten out properly, as in the case of a modern clean aeroplane without flaps. In fact, float was practically nil within a reasonable range of gliding speeds. Split flaps increased stability at the stall, and seemed better in this respect than slots and flaps; the stall with the latter took some effort to reach, but was more vicious when it did occur.

Change of trim varied; the machine with no flaps under the fuselage became nose heavy with flaps down, that with flaps extended across became tail heavy, but the effect was easy to counteract with the tail trimmer.

It had been found that in emergency the machine would just climb with flaps right down; for example, in going round again after a bad approach. He believed that the Americans used them for the take-off put down about 15 deg.

As regards the suggestion that flattening out might be more difficult owing to the greater angle through which the machine had to be rotated—that was compensated for by the fact that much less accuracy was required. Roughly, the procedure was to approach at any speed within a fair range; leave flattening out till near the ground, then bring the stick straight back quickly enough to flatten out without ballooning. As landing occurred almost at once, without float, much less accuracy was needed than if the aeroplane had to be held just off the ground for 100 yards or more.

With regard to the possibility of varying the approach angle by moving the flaps up and down, instead of side-slipping, the difficulty was that if the flaps were partly raised when coming in at a slow speed, the machine came near the stall. He suggested that flaps should be made in two parts: one to be kept down the whole time; the other to be variable by a convenient lever, so that accurate approach on to the desired point would be simplified by the variable air brake effect.

Dr. THURSTON (*communicated*): Had Mr. Alston examined the Report on Wing Tip Rotors made by the Royal Aircraft Establishment and published in the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY in February, 1934? Was he aware that the report showed (Fig. 10, page 151) that wing tip rotors gave an increased lift coefficient of as much as 2.5 if reckoned on the area of the rotor, or of at least 0.36 if reckoned on the area swept out? Was Mr. Alston aware that greater increases in lift coefficient had since been obtained with more efficient wing tip rotors?

Dr. Thurston inquired, in view of the fact that flaps influenced the air underneath the plane and hardly at all on top of the plane, whether it was not to be expected that slots would give a more powerful effect than flaps of similar area and whether the combination of slots and split flaps were not a most promising combination since one would influence the top surface and the other the bottom surface.

Had Mr. Alston made any experiments with slots used as air brakes in the manner of flaps?

Dr. Thurston also inquired if Mr. Alston had plotted the vertical rate of descent against the tangent of the gliding angle for the various landing devices, and whether he was aware that tests had been carried out at the Royal Aircraft Establishment showing that rotor wings give a much lower landing speed and a much steeper gliding path than slots or other landing devices.

Was the lecturer aware that rotor wings conformed with all the requirements set forth by the Director of Research, namely, that they gave an increase of lift of over 50 per cent, a gliding angle steeper than one in six and a low stalling speed?

And finally Dr. Thurston directed attention to Fig. 11, of the above-mentioned report, showing the effect of various landing devices on gliding characteristics, and pointed out that his experiments demonstrated conclusively that it was possible to construct a new type of machine consisting of a fixed wing machine provided with one or more windmill planes mounted on each wing.

Mr. T. E. SERBY (*communicated*): In landing problems they seem to be transferring their attention rapidly from consideration of leading edge devices to trailing edge devices, and it is advisable to bear in mind why the leading edge slot, or even the slot-cum-flap, fails rather badly as an aid to landing. The slot, of course, raises the stalling incidence too much, although it provides a very useful decrease in stalling speed. The slot and flap combination stalls at 25-30° and most aircraft have a ground incidence of less than 15°, so that if the pilot is to do a three-point landing with complete flatten out, the incidence on touching

down is far below the stall and the speed is correspondingly higher. This is shown up clearly in recent experiments at the R.A.E. on the Heinkel. On this aircraft the stalling speed, with slots and flaps in operation, was 46 m.p.h., but the touching speed for a three-point landing was 52 m.p.h., and as the " plain wing " stalling speed was 56 m.p.h., more than half the reduction in stalling speed was wasted. The trailing edge flap as a landing device certainly scores in this respect and as far as he could see, will do so unless they joined with Dr. Lachmann and do " crash " landings, as landings with rate of descent are unpleasantly called. One other alternative remains, that is to provide for changing the setting of the wings relative to the fuselage for landing.

He thought the section of the lecture dealing with pitching moments was most interesting, and certainly, any predictions about change of trim when flaps are put down need the greatest care, since the chord, position and span of the flap are all involved in the balance of pitching moments. Such brief tests as they have been able to make at Farnborough on two low wing monoplanes and one high wing monoplane equipped with Schrenk flaps show that the cutaway of the flap, *i.e.*, whether it is carried right across the centre section, is important. With no cutaway, the downwash is large enough to make the aircraft tail heavy when the flaps are put down, whereas if the flaps are not carried across, the C.P. factor seems to predominate and nose heaviness results.

With regard to ailerons on flapped wings, it appears that Zap ailerons can provide adequate lateral control, but they would appear to be heavy and draggy. Moreover, situated as they must be at the trailing edge near the wing tips, they impose severe torsional forces on the wings when they are used. This, on the Parasol monoplane, has caused wing warping which made the control poor and they had to stiffen the wings. The partial span flap which leaves the tips free for conventional ailerons seems to be adequate for landing while steering clear of this trouble.

Mr. E. F. RELF (Fellow) (*communicated*): The lecturer mentions his statement that the rapid fall of lift due to the flap will lead to trouble with the lateral control at the stall. He would like to emphasise that this statement was only intended to apply to full span flap, for which he thought it must be true. With flaps extending only to the inboard end of the ailerons, the effect would be much less marked, as the wing tips might be unstalled when the centre flapped part of the wing was stalled, and so provide a damping in roll.

REPLY TO DISCUSSION

It was very interesting to see from the slides shown by Air Commodore Chamier what was taking place in the air with flaps. These things were very difficult to take in at a glance, but they did show what was happening; there was the wake forming behind the flap and the increase in downwash behind the whole wing. With regard to the point raised as to the vicious stall, that was still a subject for discussion; model tests showed a large cliff in the lift curve when the stall occurred, but so far he did not think there had been any very drastic happenings on the full scale on that account. It might have been due to the fact that the machines had not really been stalled or it might be that stalling at full scale was not so vicious as had been suggested.

The experiences of Mr. Miles with the diruptor had been very interesting. As to the need for taking the flap right across the middle of the span, he was glad to have information from Mr. Miles, who had actually tried varying the span of the flap.

It had also been very interesting to hear from Dr. Lachmann as to what the Mattioli diruptor was supposed to do. Hitherto a great deal had been said about the diruptor, but it had not been quite known what the object really was. As to lateral stability with the diruptor, it was possible to have lateral stability

with a flat-topped lift curve at the tips or with a curve that continued rising indefinitely, and he had never been able to make out whether the diruptor got it the one way or the other. On the question of a combination of split flaps and slots, Dr. Lachmann must have misunderstood the paper, because he had not wished to give the impression that a combination of that kind was bad. Actually he only knew of one model test on such a combination which showed less lift than that predicted by Schrenk. He quite agreed with Dr. Lachmann in what he had said as to lateral stability of the tapered wing with the slot at the tip and the flap in the middle, and he was inclined to think that such an arrangement might be necessary if all that was possible was to be obtained from the flap. He regretted that the information with regard to the slotted flap given in the paper was meagre, but it was all he had available and he thought that more information was wanted in that connection. It appeared to have many advantages over the plain simple flap.

It had been suggested that by having a slotted flap pulled down, take-off requirements would probably be satisfied. One thing against the slotted flap was that the slot was not closed in normal flight and from the only test figures he had seen that gave, on a full span flap, an extra k_D of 0.001 at top speed, which was a thing to be considered.

With regard to landing attitude, he agreed with Dr. Lachmann that in the case of what had been called a direct landing, the incidence might approach that for maximum lift and it was only when one was trying to land in the normal way that it was impossible to make full use of slots.

In reply to Professor Hill, there was nothing magic, said the author, about the 10 deg. as a figure for gliding angle. It was mentioned by Mr. Gates in the report referred to by Mr. Wimperis as the best all-round figure and personally he felt there was very little to quarrel with in it. It certainly represented the old wartime standard which had been given practical test and might well be left alone. He was aware that Professor Hill's patent with the Westland Aviation Co. was for a flap very similar to the Zap, and would be interested to know who was really first.

The lag between theory and practice had been mentioned by Mr. Brewer, and his comments in this respect were very interesting. It often happened that there was a perfectly sound patent which nobody took any notice of at all, because it was not known how it worked, and it was only when somebody came along with a theory showing how it worked that people began to take an interest. The figures for landing distance given in the paper with regard to the Douglas machine were calculated out on the assumption that it was flattened out completely before touching. He could quite believe that by coming in a good deal slower and not flattening out completely, thanks to a good undercarriage, the figures mentioned in the paper could be reduced very much indeed.

There was nothing very much to say in reply to Fight Lieut. Stainforth, except to say that the idea of the semi-variable flap which could be initially lowered to a certain extent and was controllable over greater angles was an excellent idea and one which should be gone into more fully.

Replies to Written Contributions

Dr. Thurston has quoted some figures for the extra lift due to rotors taken from wind tunnel tests. I did not mention this device in the paper since the subject matter is probably well known to the Society and, further, it does not appear so promising as a flap. To make a strict comparison it is necessary to consider the extra lift coefficient (based on wing area) due to the two devices, when occupying equal amounts of wing span, *i.e.*, the outer half. On this basis the rotor (Fig. 8, Report B.A. 1083) gives $\Delta k_{L\,max}=0.11$, and a 20 per cent. chord split flap (Tech. Note 472) gives 0.165. On the basis of these figures

I can hardly agree with Dr. Thurston that " rotor wings give a much lower landing speed than slots or other landing devices."

With regard to slots and split flaps, the combination may be very good though it has been shown that flaps *do* influence the upper surface suction, in fact their extra lift is principally due to this. Leading edge slots have been used as air brakes, the braking effect being due to the increased induced drag made possible by gliding at a low speed, *i.e.*, high k_L.

Mr. Serby has given some information derived from full-scale experience upon which I have no comments to make except that he has brought out the important point that the downwash at the tail is greatly affected by the way in which the extra lift due to the flaps is distributed across the wing span.

Mr. Relf has explained that he only feared lateral instability at the stall with full span flaps and that flaps over the centre part of the wing only would probably be all right. This idea does not agree with the model tests described in T.N. 472 where it is shown that, for rectangular wings the sharp drop in the lift curve is still present when the flap tips are removed, but is rounded off when the centre portion is removed. For highly " tapered wings " T.N. 505 shows that the peak of the lift curve is rounded off when the flap tips are removed, but on the other hand Dr. Lachmann's calculations, supported by model tests, show that the local incidence at the unflapped wing tips reaches stalling value, thereby producing instability at an even lower incidence than that for maximum lift of the whole wing. Experience alone can show how important this effect may be.

The PRESIDENT: In proposing a hearty vote of thanks to Mr. Alston, he said the interest in the subject he had dealt with was well shown in that so many people had come out on such a bad night to take part in the discussion and to listen to the lecture. His own view of this problem was that although they might think they knew a great deal about this subject, very few people knew anything about it at all, and it was obviously a subject which would have to be pursued very vigorously in the near future. He himself rather liked to think of the feats of aviation performed by that simple domestic creature which in the scientific world was so apt to be ignored, namely, the household fly, and it was not to be supposed that any aviator even from the Royal Aircraft Establishment would ever be able to emulate the household fly by landing upside down on the ceiling! There were, however, other things about at this time of the year which excited him and one of them was the pheasant. To see a pheasant fly perfectly vertically straight up in the middle of a wood, breaking branches and knocking leaves about, and then landing with a three-inch travel on his undercarriage was really a thing which ought to be studied because it introduced a point which Dr. Lachmann had mentioned, namely, that the standard way of landing with the engine cut off might not be the right way of landing. After all, the pheasant used all his engine power and did his landing with full power. Undoubtedly, as many speakers had said, this subject must be pursued further, because it butted in to the very essence of flying from the design point of view and also from the safety point of view.

The vote of thanks was given with enthusiasm and the meeting closed.

NATIONAL RESEARCH LABORATORIES

REPORT No. PAA-22

THE AERODYNAMIC CHARACTERISTICS OF AIRCRAFT SKIS AND THE DEVELOPMENT OF AN IMPROVED DESIGN *

BY

J. J. GREEN and G. J. KLEIN

OTTAWA. FEBRUARY 12, 1935

SUMMARY

Introduction—Reasons for Investigation

Existing information on the aerodynamic characteristics of aircraft winter landing gear is very meagre and it was therefore desirable to test as many full size skis as possible in order to collect data concerning the various types of skis in actual use.

It was known that the air resistance of existing types is quite high and the experiments were intended to explore the possibilities of producing an improved type of ski having considerably lower air resistance.

The large pitching moments on present types of skis give rise to serious problems in trimming gear design, especially on high performance aircraft. The experiments aimed at producing a ski on which the pitching moments would be considerably reduced in order that the use of exterior trimming cables might be avoided.

Range of Tests—Part I.—Collection of Data on Existing Types

A standard wind speed of 100 ft./sec. was used throughout the tests. The lift, drag and pitching moment were measured for eight full size skis and one-half scale model ski, over an incidence range of from $-20°$ to $+25°$. All the skis are types used at the present time by the R.C.A.F. or commercial operators.

The air resistance of two representative types of trimming gear was also measured.

The air resistance of a full size aeroplane wheel was measured for comparison with the ski for the same aeroplane.

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Results of Tests

Diagrams of the resultant force vectors on the various skis have been included.

The lift and moment about the axle centre line plotted as coefficients show a remarkable agreement between the various skis tested. This agreement would be more striking if the incidences had been referred to the no-lift and no-moment angles as zero. The results of previous tests on two other full size skis have been included on the moment diagram.

The agreement between the drag coefficients is not good.

The trimming cables were found to contribute some 33 per cent. (approx. 7lb.) of the total minimum drag of the ski with its trimming gear.

The full size wheel had only one-third of the minimum resistance of the ski and its trimming gear.

Range of Tests—Part II.—Development of an Improved Type of Ski

A standard wind speed of 100 ft./sec. was used throughout the tests. A half scale model of one of the full size skis was used as a basis for the new design. No pedestal was included on this model. By progressive modification, a new design was evolved. Lift, drag and pitching moment about the axle centre line were measured after each modification had been made. In all, nine models were thus tested.

Results of Tests

The lift and drag in pounds and the pitching moment in foot pounds have been plotted over an incidence range $-20°$ to $+25°$ for the nine models. The progressive improvement in drag and pitching moment is well shown. The minimum drag of the ski has been reduced by more than 50 per cent. This indicates that this type of ski with an enclosed pedestal and internal trimming gear should have only 20 per cent. of the drag of the original ski with its exposed pedestal and trimming cables. On this basis, the ski gear has less drag than the wheel, and improvement in performance should result on changing from wheels to skis.

Over an incidence range $-20°$ to $+20°$, the change in pitching moment has been reduced from 62ft. lb. to 16ft. lb. (half scale models at 100 ft./sec.).

A resultant force vector diagram for the final design is included and shows how the trimming problems have been reduced.

Conclusions

The tests on the full size skis indicate that there is opportunity for considerable aerodynamic improvement in existing skis by reducing the large air resistance and by reduction of the slope of the pitching moment curve. These conclusions have been justified by the results of the second part of the tests in which a new design of ski has been developed which allows an 82 per cent. reduction in the drag of the ski installation, coupled with very much improved pitching moment characteristics.

In an appendix to the report, certain recommendations are made with a view to utilising the improved design to the best advantage.

Further Developments

A full size pair of skis are being modified to the improved design by the Department of National Defence for full scale trials on a Hawker " Audax."

Introduction—Reasons for Investigation

Very little published information on the aerodynamic characteristics of aircraft winter landing gear is in existence. Measurements of the pitching moments on three full size skis are given in an earlier report of the National Research Laboratories (Reference 1) and a second report (Reference 2) described experiments in which attempts were made to simplify the problems of trimming the skis on a high performance aeroplane, either by the use of a turn-up at the rear of the ski or by the addition of a trimming aerofoil.

In view of this lack of data, it seemed desirable to undertake a systematic testing in the wind tunnel of as many full size skis as possible and of types representative of those in actual use at the present time. It was felt that the accumulation of this information would not only be of assistance to the designers and operators in their immediate problems, but would form a basis and guide in future designs.

The very considerable decrease in performance which results when wheels are replaced by skis is evidence of the high air resistance of skis. This is particularly marked when dealing with high performance military aircraft. It was therefore intended that, after the aerodynamic characteristics of the full size skis had been measured, experiments should be undertaken to explore the possibilities of producing an improved type of ski having considerably lower air resistance than the types in use at the present time.

To take care of the large unstable aerodynamic pitching moments on the ski, which are the result of placing the pedestal well back with reference to the snow bottom—a position which is necessary for efficient operation on the snow—the present practice is to incorporate very heavy trimming gear in the form of rubber shock cords and check cables attached to the front and rear of the skis. This entails extra air resistance and, in the case of high performance aircraft, the moments to be controlled are so large and the trimming gear consequently so stiff that there is no flexibility when taxying over snow drifts. The design of trimming gear which will allow sufficient flexibility when taxying, so that the requirement of 15° upward travel and 32° downward travel for the front of the ski can be achieved without strain and which will yet be stiff enough to stabilise the large unstable moments in flight, presents some difficulties. In developing a new design of ski, the experiments aimed, not only at reducing air resistance, but also at reducing the magnitude of the unstable pitching moments on the ski in order that some form of internal trimming gear might be used, thus avoiding the use of exterior trimming cables.

The use of a turn-up at the rear of the ski was found to be quite satisfactory in preventing the existence of negative moments tending to drop the front of the ski, but this still left fairly large positive moments to be accommodated, and further, the ski drag was so large that the top level and cruising speeds of the aeroplane were seriously reduced.

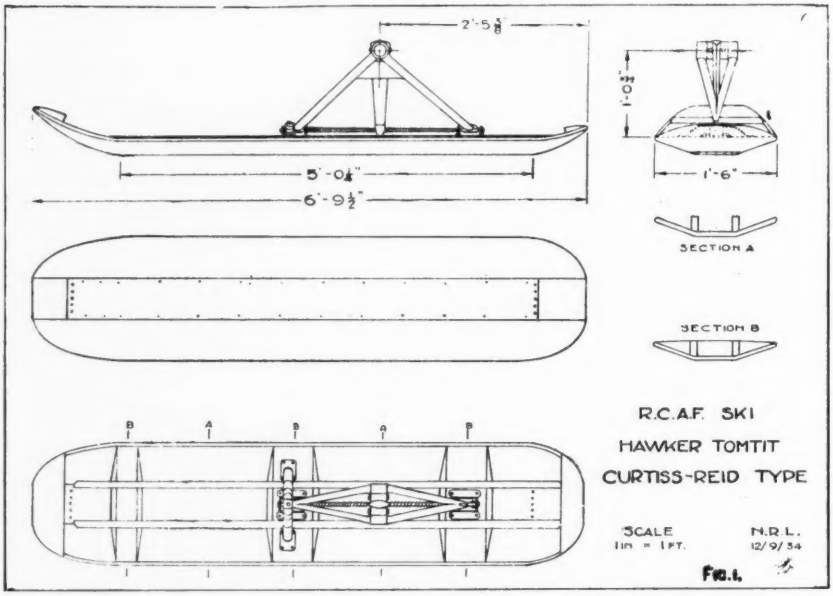
PART I.—TESTS ON FULL-SIZE SKIS

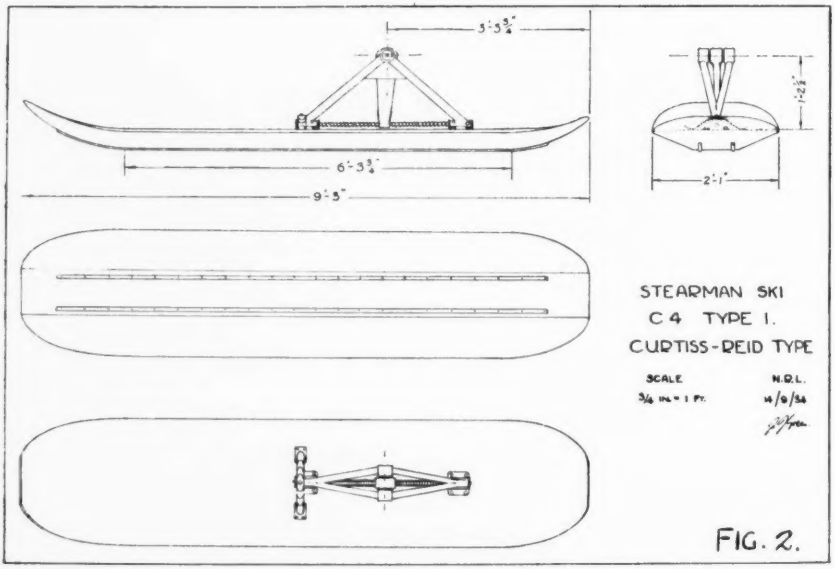
Range of Tests

The following skis were tested and four view drawings of them are given in Figs. 1 to 9:—

Fig. 1.—Hawker Tomtit Ski, Curtiss-Reid self-trimming type, 1,800lb. aircraft.
Fig. 2.—Stearman Ski (C.4, type 1), Curtiss-Reid type, 3,500lb. aircraft.
Fig. 3.—Siskin IIIA Ski, R.C.A.F. size C.
Fig. 4.—Atlas Ski, R.C.A.F. size D.
Fig. 5.—Bellanca Ski, R.C.A.F. size E (type 18).
Fig. 6.—Bellanca Ski, R.C.A.F. size E shortened by 6in. (type 2).

Fig. 7.—Hawker Audax, R.C.A.F. size E with a rear turn up.
Fig. 8.—D.H. 61 Ski, Ontario Provincial Air Service, Box Ski.
Fig. 9.—D.H. Moth Ski, Millar Mineral Exploration Co.





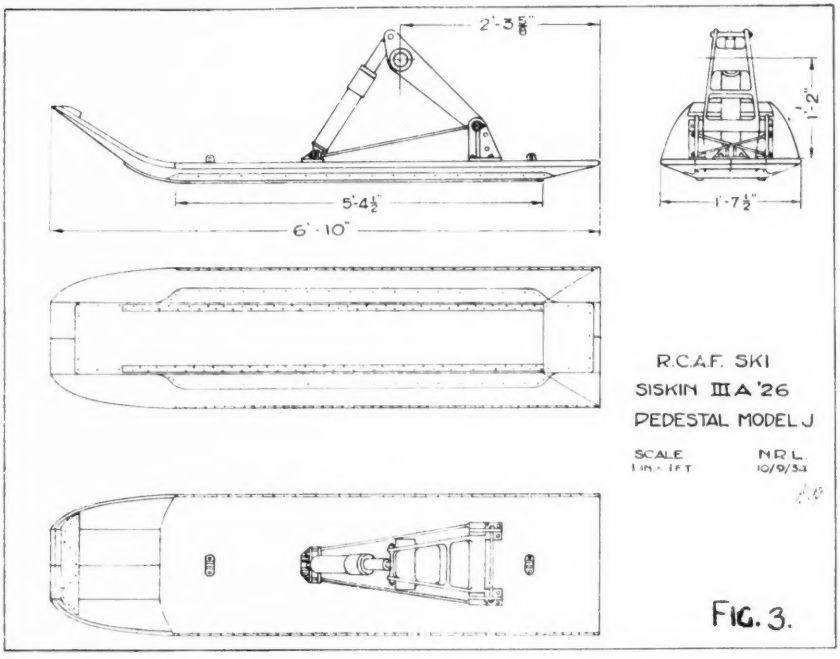

2'-3⅝"
1'-2"
5'-4½"
1'-7½"
6'-10"
R.C.A.F. SKI
SISKIN IIIA '26
PEDESTAL MODEL J
SCALE
1 IN. = 1 FT.
N.R.L.
10/9/34

FIG. 3.

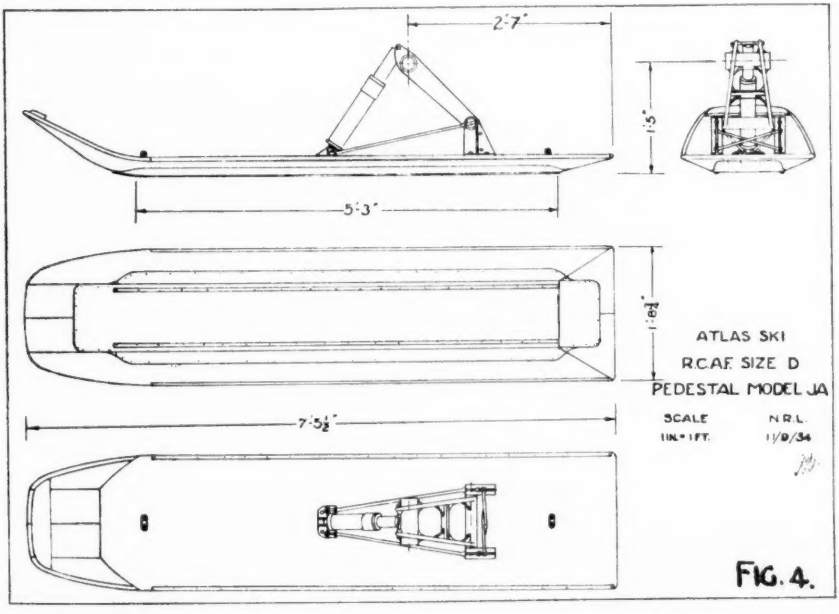

2'-7"
1'-5"
5'-3"
1'-8½"
7'-5½"
ATLAS SKI
R.C.A.F. SIZE D
PEDESTAL MODEL JA
SCALE
1 IN. = 1 FT.
N.R.L.
11/9/34

FIG. 4.

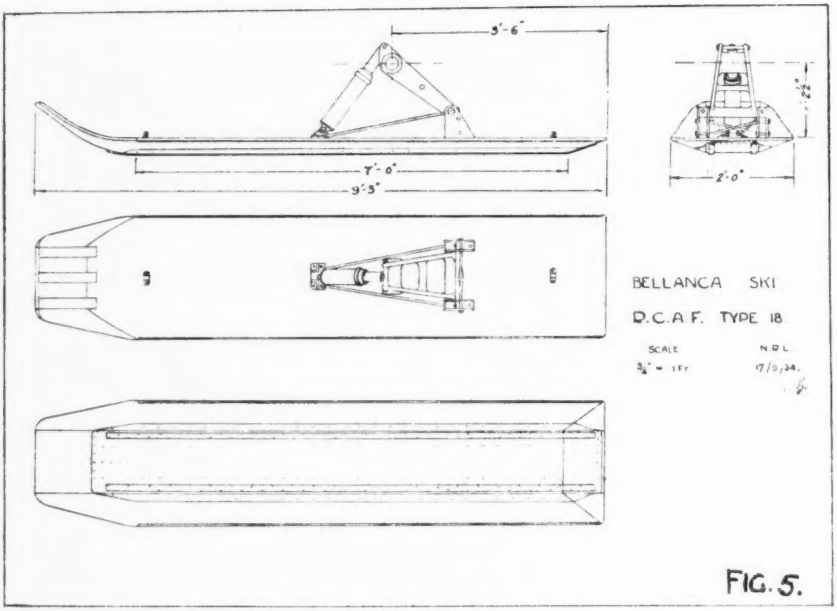

5'-6"
7'-0"
9'-3"
2'-0"
BELLANCA SKI
R.C.A.F. TYPE 18
SCALE
N.R.L.
17/9/34.

FIG. 5.

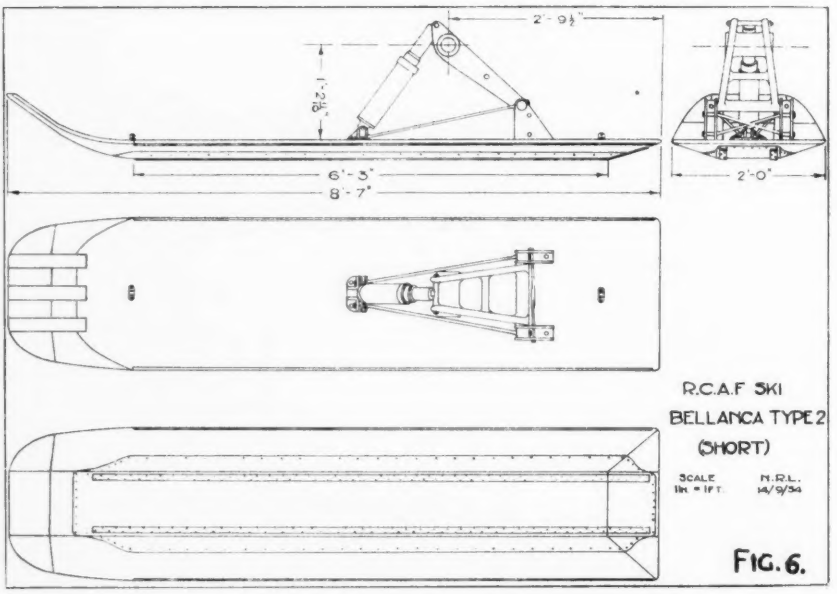

2'-9½"
1'-2½"
6'-3"
8'-7"
2'-0"
R.C.A.F SKI
BELLANCA TYPE 2
(SHORT)
SCALE
N.R.L.
14/9/34

FIG. 6.

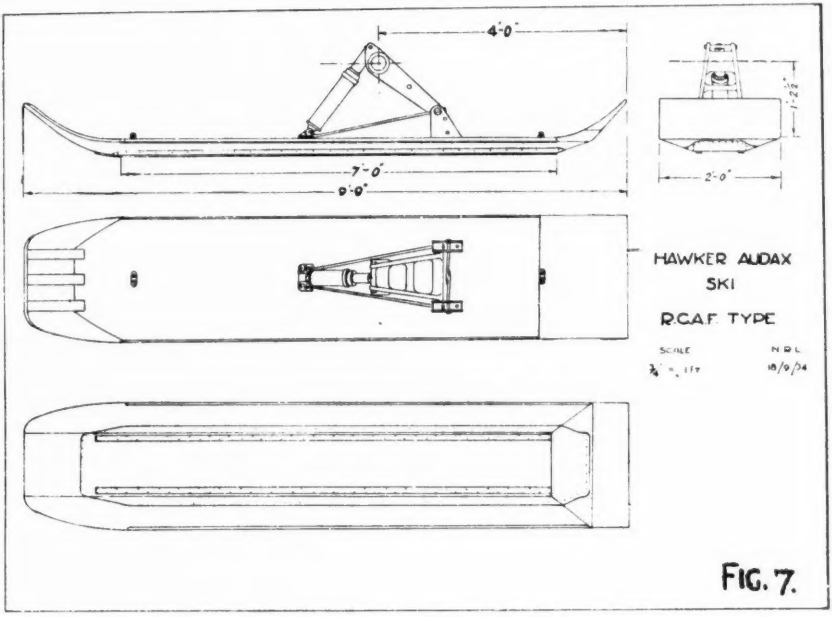

4'-0"
7'-0"
9'-0"
2'-0"
HAWKER AUDAX
SKI
R.C.A.F. TYPE
SCALE
N.P.L.
18/9/34

FIG. 7.

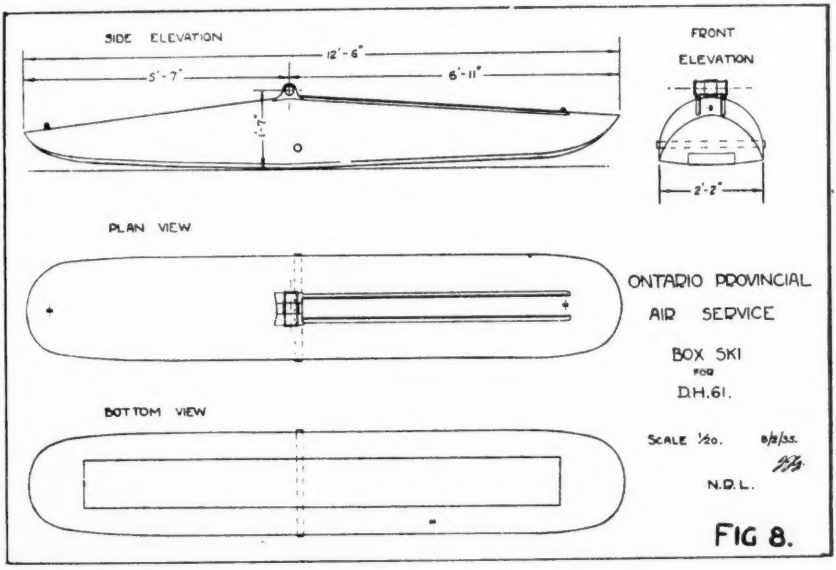

SIDE ELEVATION
12'-6"
5'-7"
6'-11"
FRONT
ELEVATION
2'-2"
PLAN VIEW
BOTTOM VIEW
ONTARIO PROVINCIAL
AIR SERVICE
BOX SKI
FOR
D.H.61.
SCALE 1/20.
8/2/33.
N.P.L.

FIG 8.

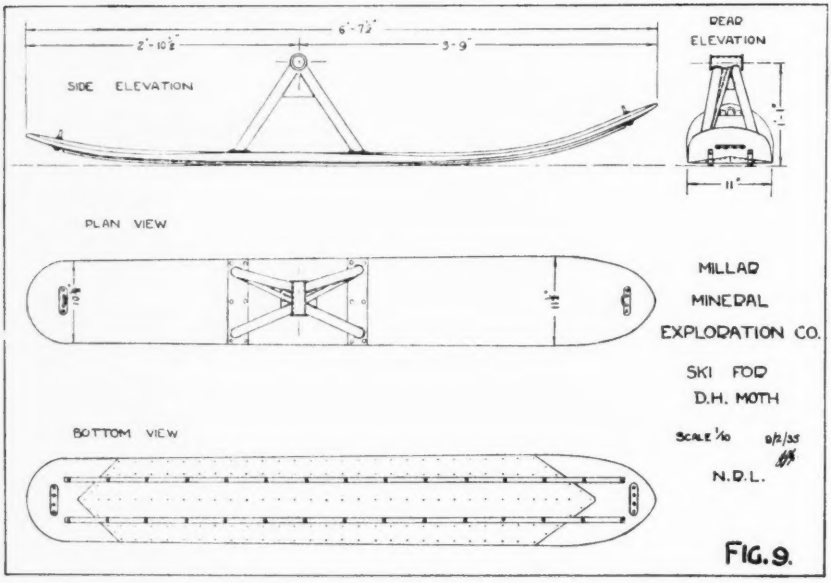


FIG. 9.

In the case of the D.H. 61 ski, this was too large to test and an accurate half scale model was therefore constructed, with all details reproduced, which was tested instead. It was assumed that scale effect in testing a half size model of a ski would be negligible. Scale effect on pitching moments in earlier tests on other skis (Reference 1) had been found to be very small and it was felt that the inclusion of data on the half scale model with that for the full size skis is justifiable.

The skis were supported from the subframe balance by means of a $1\frac{1}{8}$in. diameter steel shaft, 32in. long, attached near the front of the ski. The ends of the shaft were turned down and fitted with ball bearings which were housed in fittings at the apices of two V's formed by streamlined struts, the upper ends of which were attached to the four corners of the subframe.

The skis were all tested in an inverted position, the length of the supporting struts being such that the supporting shaft was in the horizontal plane through the centre of the 9ft. jet of the tunnel. Vertical tail wires attached to the rear of the ski were fixed at their upper ends to the quadrant beam and served to support the ski. Adjustment of the incidence of the ski was then effected by unclamping and moving the quadrant beam up or down.

A standard wind speed of 100 ft./sec. was used throughout the tests. Lift, drag and pitching moment about the supporting shaft were measured every 5° from $-20°$ to $+25°$ and the pitching moment about the axle centre line was calculated from the results. In all cases, due correction has been made for the drag of the supporting shaft, struts and tail wire. The datum for incidence measurement has been taken as the flat bottom of the ski, and in those two cases where the bottom is curved the datum was taken as the tangent to the bottom at the point where a line drawn from the axle centre line perpendicular to the ski bottom meets it.

In addition to the above tests, the drag of the following types of trimming gear was also measured:—

Ski Type.	No. of Strands of Shock Cord.	Diam.	Length.	Length of Flexible Check Cable $\frac{1}{8}$in. diam.
Bellanca, Type 2 (Short)	Front 4	$\frac{1}{2}$in.	21in.	112$\frac{1}{2}$in.
	Rear 4	$\frac{1}{2}$in.	15in.	55in.
Atlas R.C.A.F. " D "...	Front 3	$\frac{1}{2}$in.	30in.	56in.
	Rear 3	$\frac{1}{2}$in.	16in.	46in.

In order to give some indication of the magnitude of the increased air resistance when wheels are removed and skis fitted, the drag of a full size Bellanca (or Fairchild " 71 ") wheel was measured at 100 ft./sec. for comparison with the drag of the two types of Bellanca ski. The dimensions of the wheel are given on a drawing (Fig. 22).

Results of Tests

Figs. 10 to 18 are diagrams of the resultant force vectors at the various incidences for all the skis tested.

The lift coefficients, drag coefficients and coefficients of the pitching moment about the axle centre line have been plotted in Figs. 19, 20 and 21. These coefficients are defined as follows:—

$$K_L = L/\rho S V^2$$
$$K_D = D/\rho S V^2$$
$$K_M = M/\rho S L V^2$$

where L = lift in lbs., D = drag in lbs. and M = moment about axle centre line in ft. lbs.

Positive moments are those tending to increase the incidence of the ski in the positive direction.

ρ = air density = 0.002378 slugs/c. ft.
V = wind speed in ft./sec. = 100.
S = overall length of ski in ft. × overall width of ski in ft.
L = overall length of ski in ft.

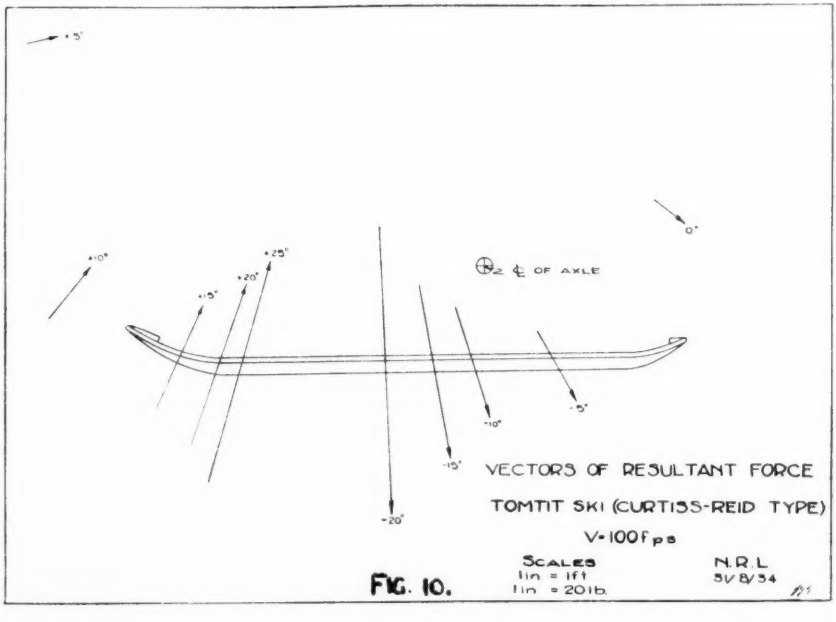


FIG. 10.

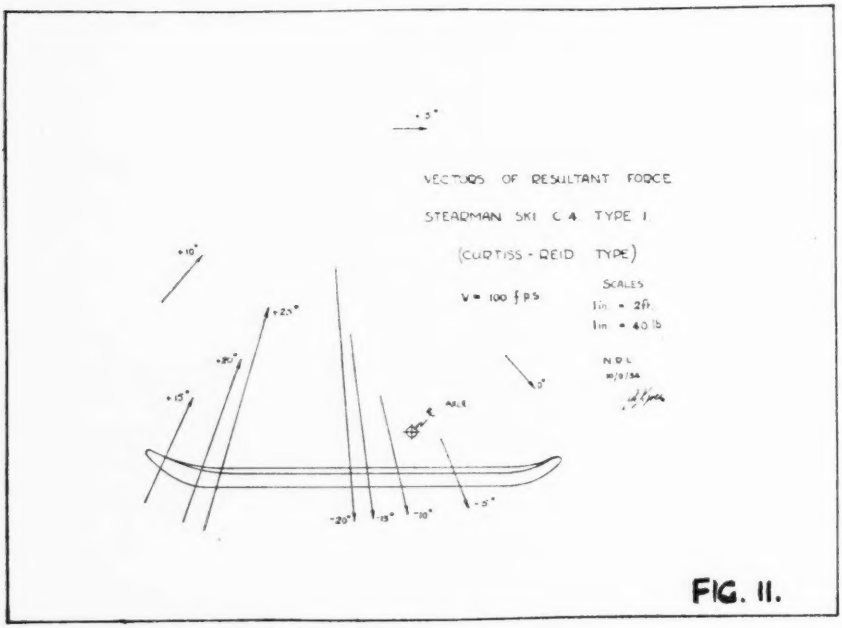

VECTORS OF RESULTANT FORCE
STEARMAN SKI C.4 TYPE I
(CURTISS-REID TYPE)
V = 100 f.p.s.
SCALES
1 in. = 2 ft.
1 in. = 40 lb.
N.R.L.
+10°
+25°
+20°
+15°
AXLE
-20°
-15°
-10°
-5°

FIG. 11.

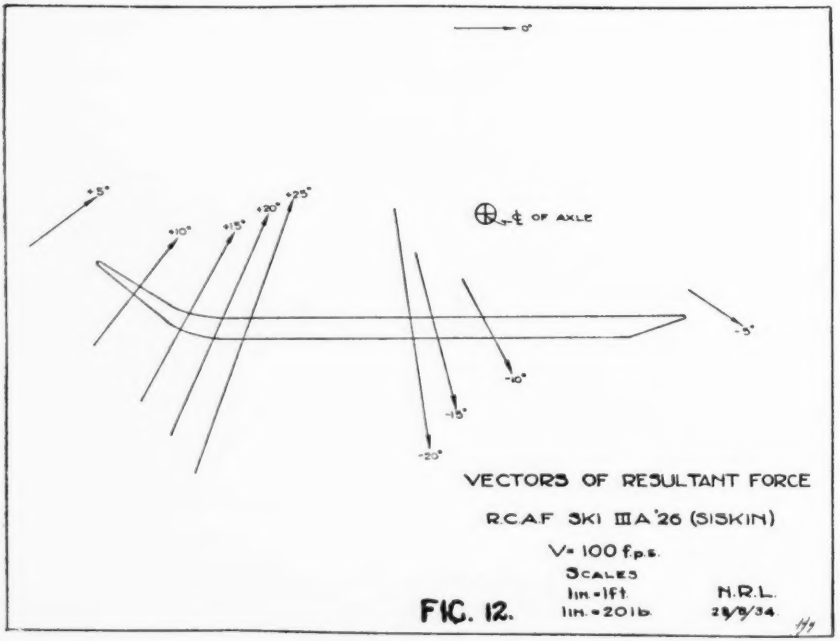

+5°
+10°
+15°
+20°
+25°
℄ OF AXLE
-5°
-10°
-15°
-20°
VECTORS OF RESULTANT FORCE
R.C.A.F. SKI IIIA '26 (SISKIN)
V = 100 f.p.s.
SCALES
1 in. = 1 ft.
1 in. = 20 lb.
N.R.L.
28/8/34

FIG. 12.

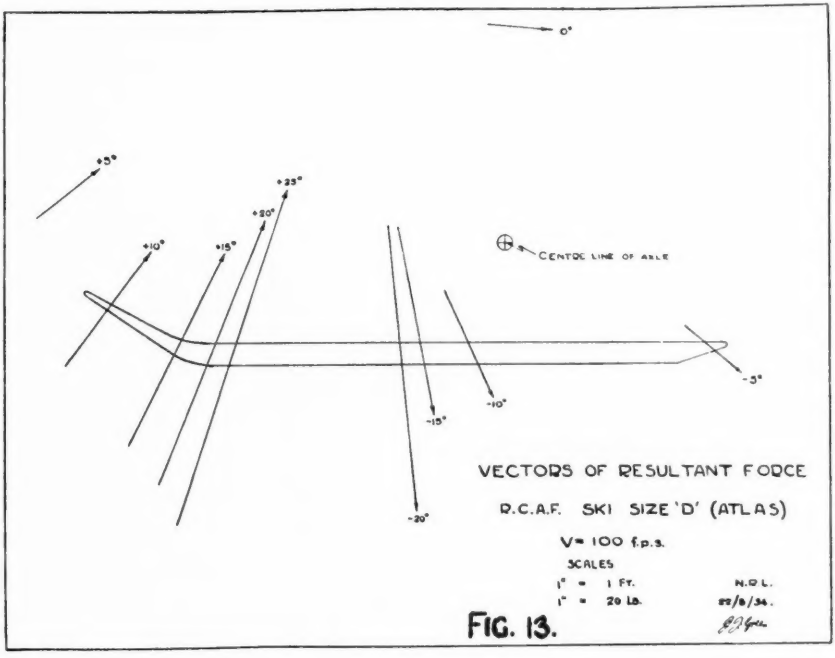

0°
+5°
+10°
+15°
+20°
+25°
CENTRE LINE OF AXLE
-5°
-10°
-15°
-20°
VECTORS OF RESULTANT FORCE
R.C.A.F. SKI SIZE 'D' (ATLAS)
V= 100 f.p.s.
SCALES
1" = 1 FT.
1" = 20 LB.
N.R.L.
22/6/34.

FIG. 13.

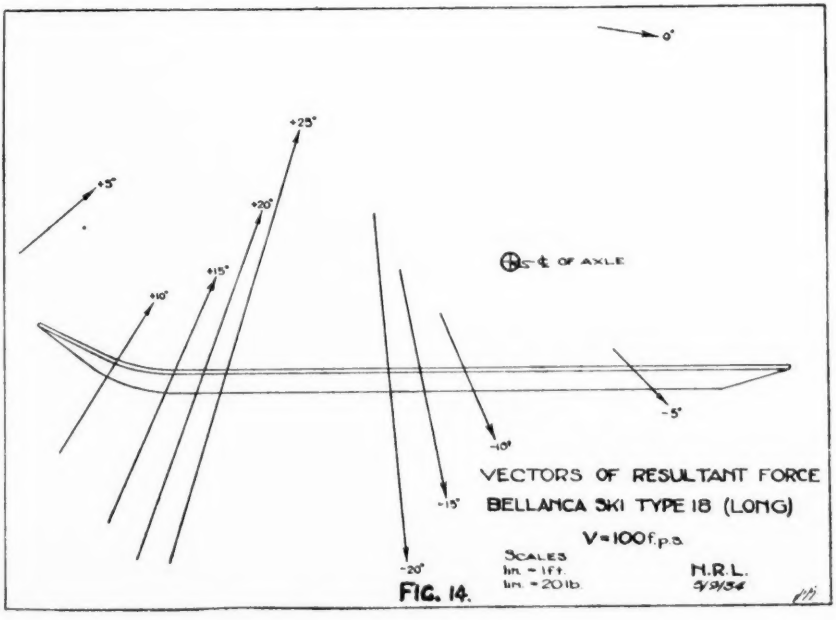

0°
+5°
+10°
+15°
+20°
+25°
℄ OF AXLE
-5°
-10°
-15°
-20°
VECTORS OF RESULTANT FORCE
BELLANCA SKI TYPE 18 (LONG)
V=100 f.p.s.
SCALES
1in. = 1 ft.
1in. = 20 lb
N.R.L.
5/3/34

FIG. 14.

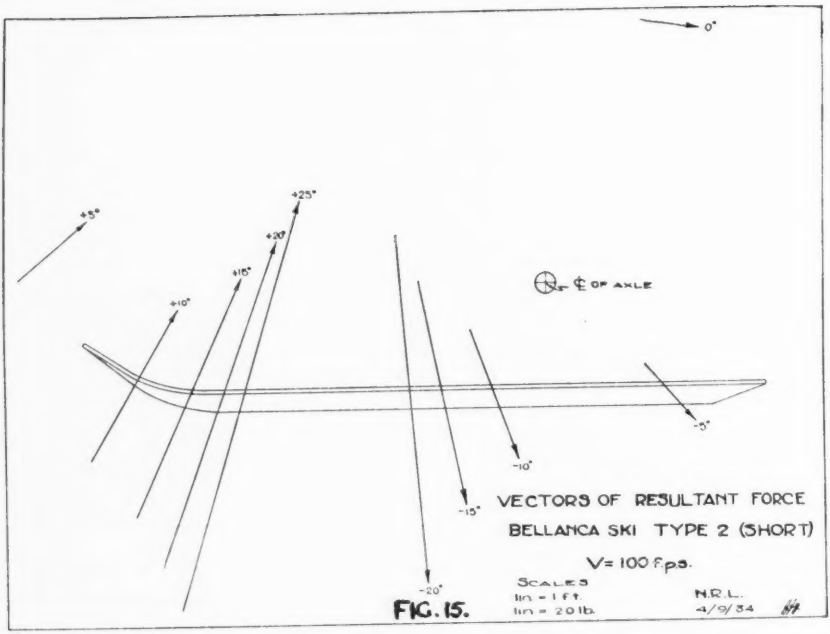

0°
+5°
+10°
+15°
+20°
+25°
℄ OF AXLE
-5°
-10°
-15°
-20°
VECTORS OF RESULTANT FORCE
BELLANCA SKI TYPE 2 (SHORT)
V= 100 f.p.s.
SCALES
lin. = 1 ft.
lin. = 20 lb.
N.R.L.
4/9/34

FIG. 15.

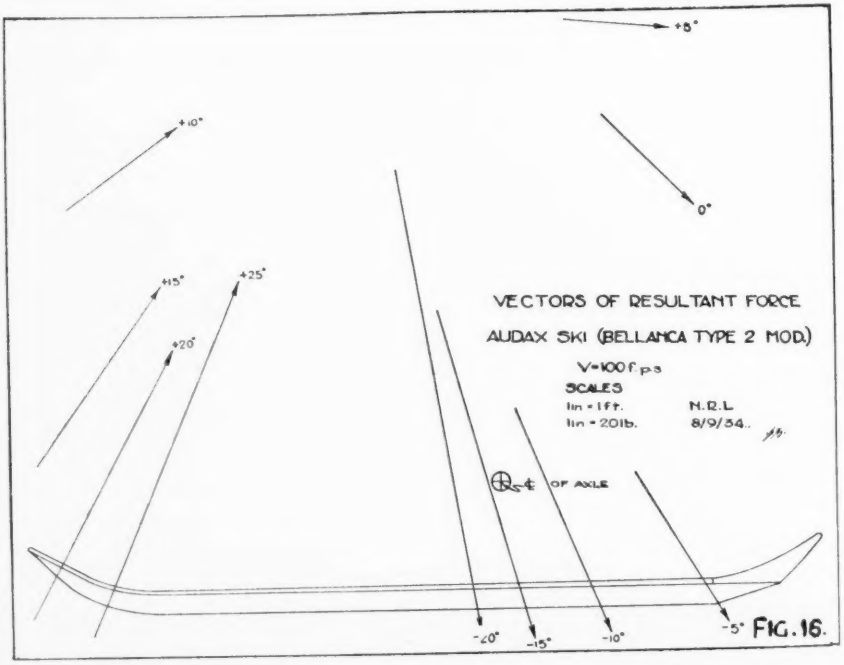

+5°
+10°
0°
+15°
+25°
+20°
VECTORS OF RESULTANT FORCE
AUDAX SKI (BELLANCA TYPE 2 MOD.)
V=100 f.p.s
SCALES
lin = 1 ft.
lin = 20 lb.
N.R.L
8/9/34.
℄ OF AXLE
-20°
-15°
-10°
-5°

FIG. 16.

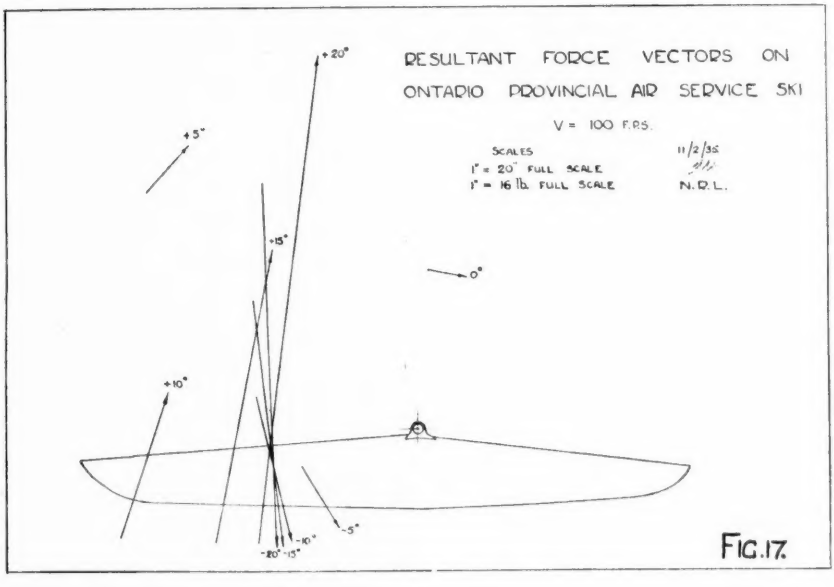

RESULTANT FORCE VECTORS ON
ONTARIO PROVINCIAL AIR SERVICE SKI
V = 100 F.P.S.
SCALES
1" = 20° FULL SCALE
1" = 16 lb. FULL SCALE
11/2/35
N.R.L.
+20°
+5°
+15°
0°
+10°
-5°
-10°
-20°
-15°

FIG. 17.

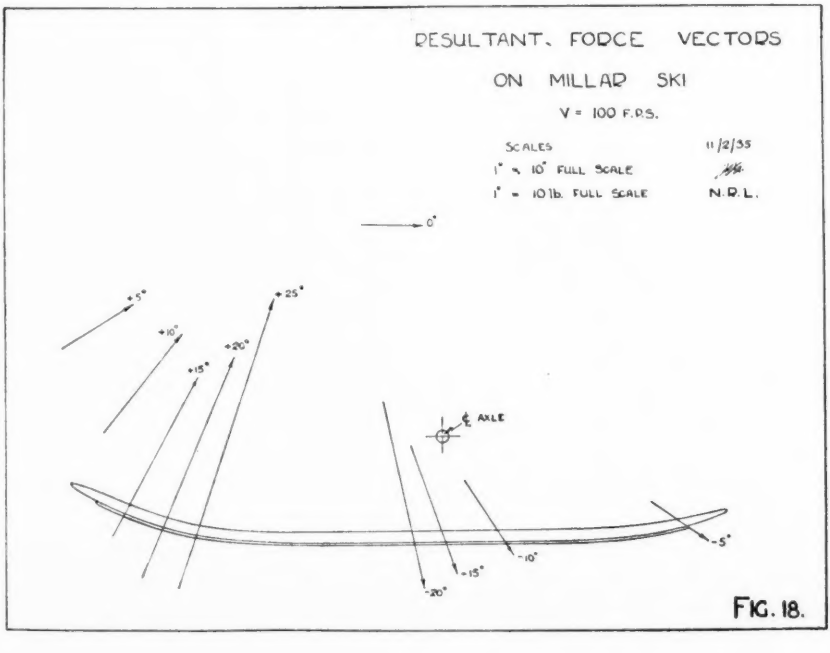

RESULTANT FORCE VECTORS
ON MILLAR SKI
V = 100 F.P.S.
SCALES
1" = 10° FULL SCALE
1" = 10 lb. FULL SCALE
11/2/35
N.R.L.
0°
+5°
+10°
+15°
+20°
+25°
℄ AXLE
-5°
-10°
-15°
-20°

FIG. 18.

In Fig. 19 it is seen that the lift coefficients of the skis fall in a group with the exception of those three skis in which turn-up exists at the rear. The maximum displacement occurs in the case of the ski with the most pronounced turn-up, viz., the " Audax " ski. It is obvious that, if the coefficients had been plotted against incidence with the no-lift angle as zero datum, the agreement

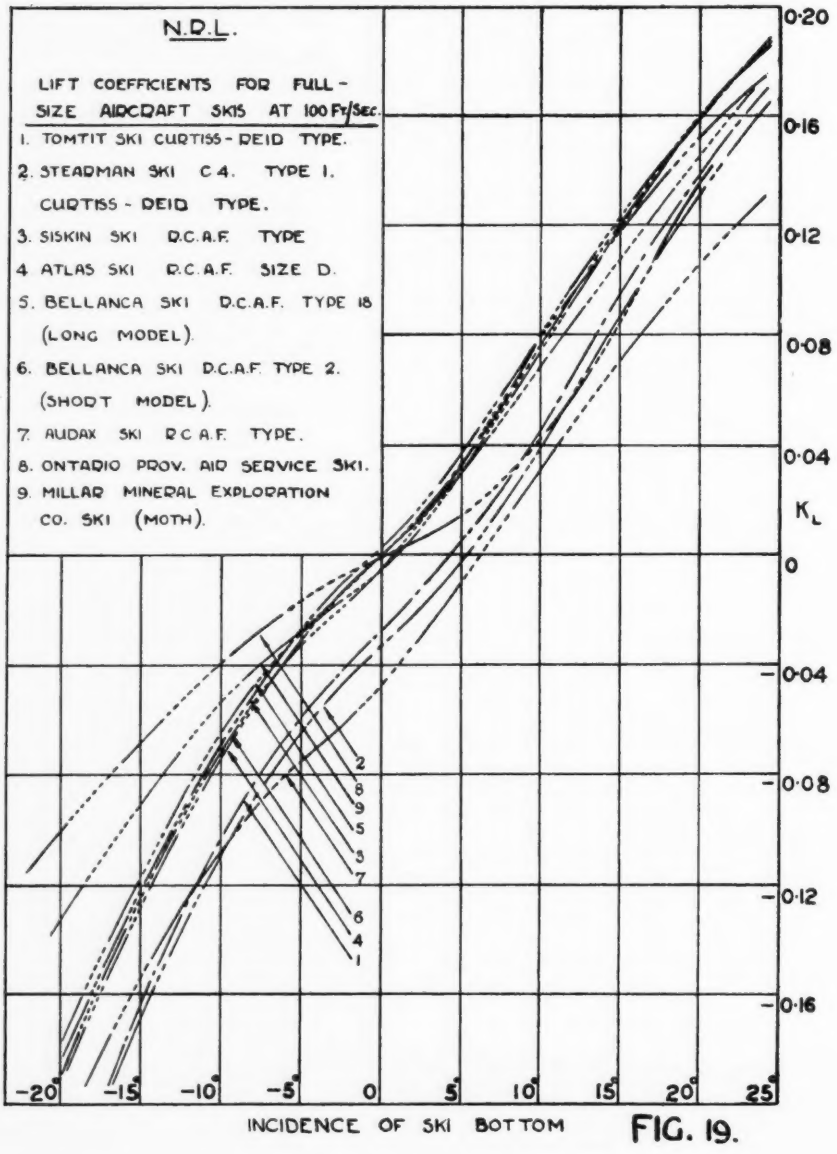


FIG. 19.

between the curves would be even more marked. In the case of the D.H. 61 box ski (Ontario Provincial Air Service) the slope of the lift curve is considerably reduced near the no-lift incidence. This ski differs considerably from the other types tested and would therefore be expected to have slightly different characteristics. Similarly, the Millar ski, which has a pronounced curvature at the

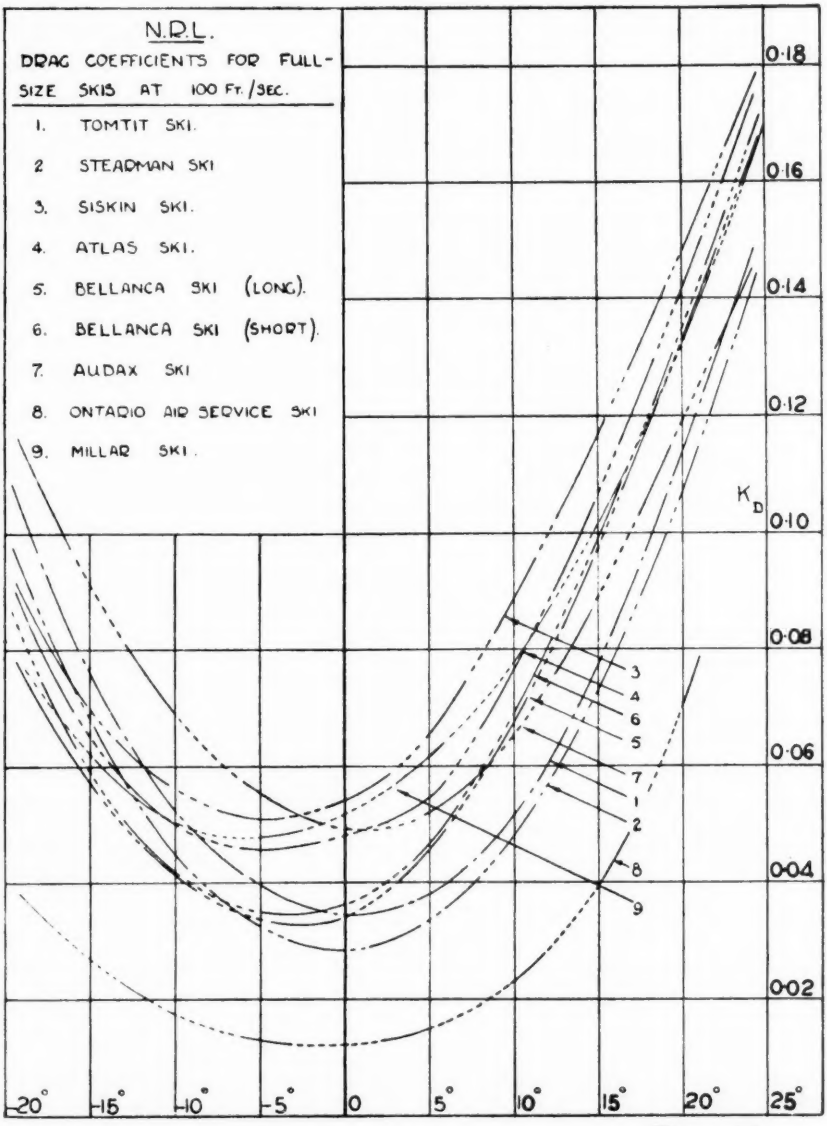


FIG. 20

front end, shows a tendency to depart from the general characteristics at negative incidences.

As would be expected, the magnitude of the lift forces is small and of no practical importance.

The drag coefficients given in Fig. 20 show wide scattering between the various skis. This is to be expected on account of the widely different pedestal types which contribute a considerable percentage of the total drag in each case.

The beneficial effect of even the simplest type of cowling on the ski is

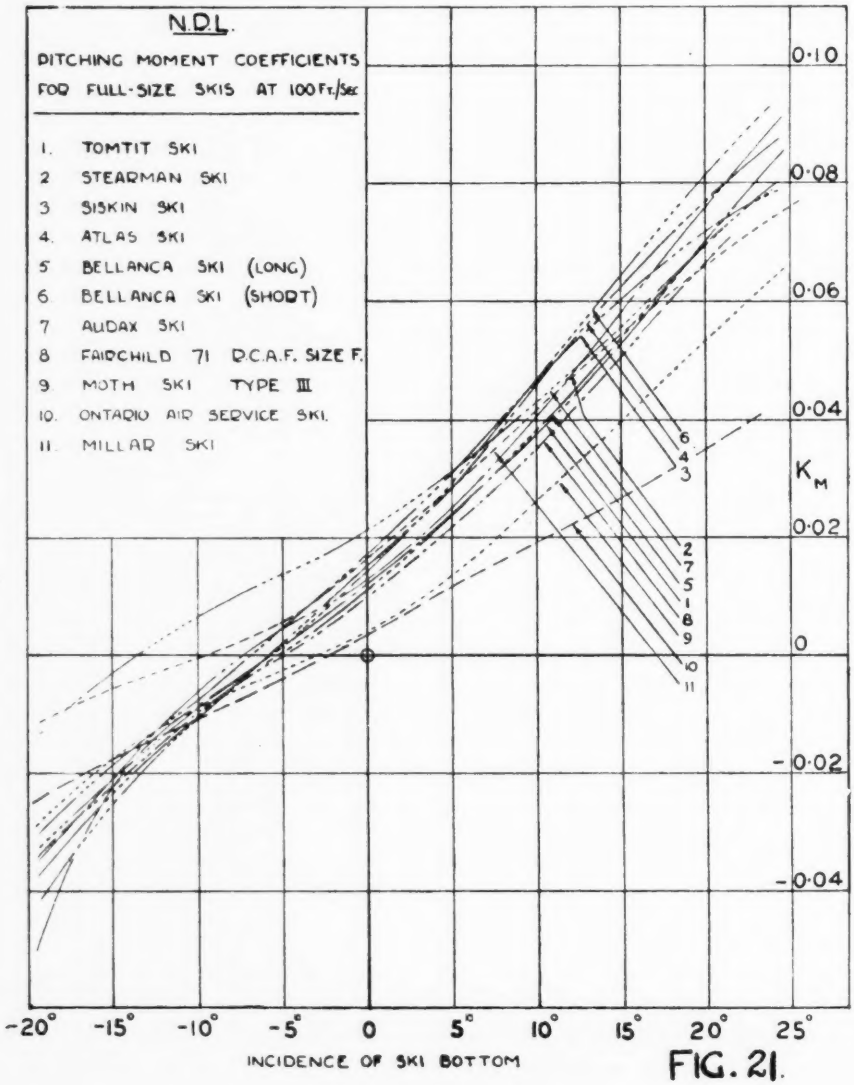


FIG. 21.

strikingly shown in the case of the Ontario Provincial Air Service ski which has a much lower minimum drag value than any of the others.

The pitching moments on two full size skis as given in an earlier report (Reference 1) have been included with results from the present tests (Fig. 21). These skis are:—D.H. Moth ski, Type III and Fairchild 71 ski, R.C.A.F., Type F.

The moment curves show close agreement between skis of various sizes of the same type and even among some of different type. If the moments had been plotted against incidence with the no-moment angle as zero datum, the agreement would be more pronounced.

The effect of rear turn-up indicated in Reference 2 is again demonstrated in the present tests by the shape of the curve for the " Audax " ski.

Close similarity is evident in the shape of curves 9 and 11, which are both for Moth skis of very similar shape except that one has a much more pronounced curvature along its length.

The much reduced slope of the moment curve in the case of the Ontario Provincial ski is due to two causes—the improved aerodynamic shape due to simple cowling and the fact that the pedestal is slightly more forward than is the case with other types of ski.

On the whole, the slope of the pitching moment curves for skis is very high and leads to very large pitching moments in the case of big skis on high speed aircraft.

The results of the drag measurements on the trimming gear for the Bellanca and Atlas skis are given in the following table and for comparison the minimum drag of the skis in pounds is given at the same test speed of 100 ft./sec.:—

Ski.	Wind Speed 100ft./sec. Minimum Drag (lb.)	Drag of Trimming Gear (lb.)
Bellanca Type 2 (Short) ...	14.10	7.62
Atlas R.C.A.F. " D " ...	14.24	7.44

The necessity for using ski trimming gear thus causes an increase of from 52 to 54 per cent. in the minimum drag of the ski installation.

The measurements of wheel drag gave a value of 7.26lb. for the resistance of a single full size wheel at 100 ft./sec. The minimum drag of the skis with their trimming gear is compared with the wheel drag in the following table:—

Aircraft.	Drag in lbs. at 100 ft./sec. 2 Skis Type (2) + Trimming Gear.	1 Pair of Wheels.
Bellanca ...	Minimum drag=43.44	15.52

This large difference between the drag of wheels and skis explains the drop in performance when changing from wheels to winter landing gear.

Fig. 35 includes curves of the drag of a single ski (Bellanca Type 2) with and without trimming cables and also the drag of the single wheel.

Part II.—Development of an Improved Type of Ski

Range of Tests

A standard wind speed of 100 ft./sec. was used throughout the tests. A half scale model of one of the full size skis, the Bellanca Type 2 (Short) was used as a basis. This ski has a very satisfactory performance on a variety of snow conditions and for this reason, in developing a new type of ski, the snow bottom was retained unaltered and the location of the axle with respect to it was unchanged. No pedestal was included on the model during the development stages. The method of suspension was the same as for the full size skis except that a $\frac{5}{8}$in. diameter shaft was used instead of the $1\frac{1}{8}$in. diameter shaft and the tail wires

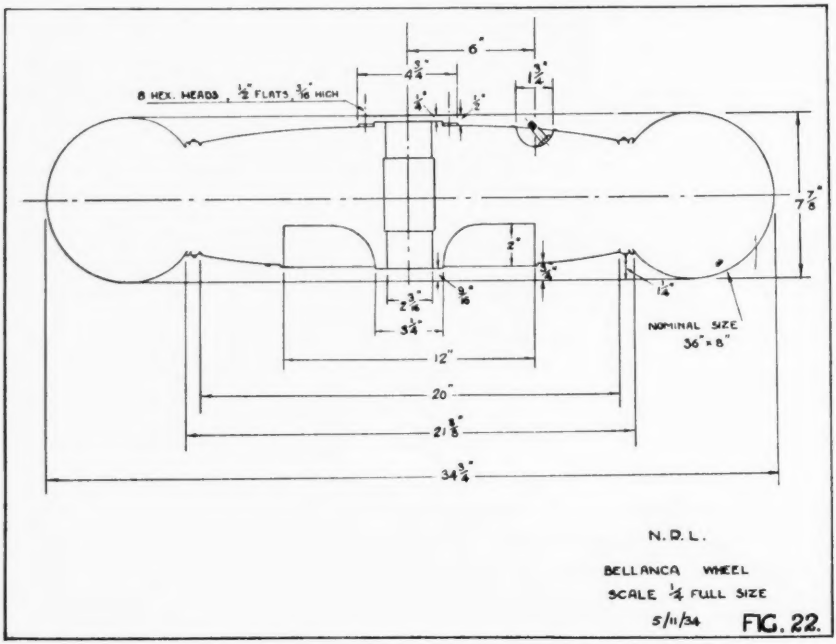
were of lighter gauge. Lift, drag and moment were measured every 5° from −20° incidence to +25° and moments were calculated about the position corresponding to the axle centre line for every modification to the model.

The general trend of the modifications were twofold:—

(1) To provide the ski with a cowling which would be so shaped that it gave the ski as clean a streamline form as possible.

(2) To lengthen the ski body without affecting the area of that portion which contacts with the snow. To do this, the after-body was lifted clear of the snow so that even with the maximum upward travel of 15° at the front of the ski, the lengthened portion of the ski would only just be coming into contact with the snow. The reason for lengthening the ski was to decrease its instability in the air by increasing the length of ski aft of the supporting axle.

Nine different models were tested.



Results of Tests

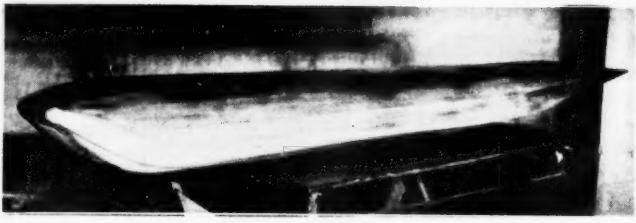
Drawings of the nine models from the basic form to the final improved type are given in Figs. 23 to 30 and a plate of photographs of the more important stages in the development is included. In view of the changes in overall length during the development, it would bestow an unfair advantage on the developed model to compare the various models on a basis of coefficients derived by dividing the forces by the overall length and the moments by the square of the overall length. Consequently the lift and drag are given in pounds and the moments in ft. lbs. These results for the various stages in the development are plotted in Figs. 31, 32 and 33.

MODEL NO. 2

MODEL NO. 4

MODEL NO. 6

MODEL NO. 7



MODEL NO. 9

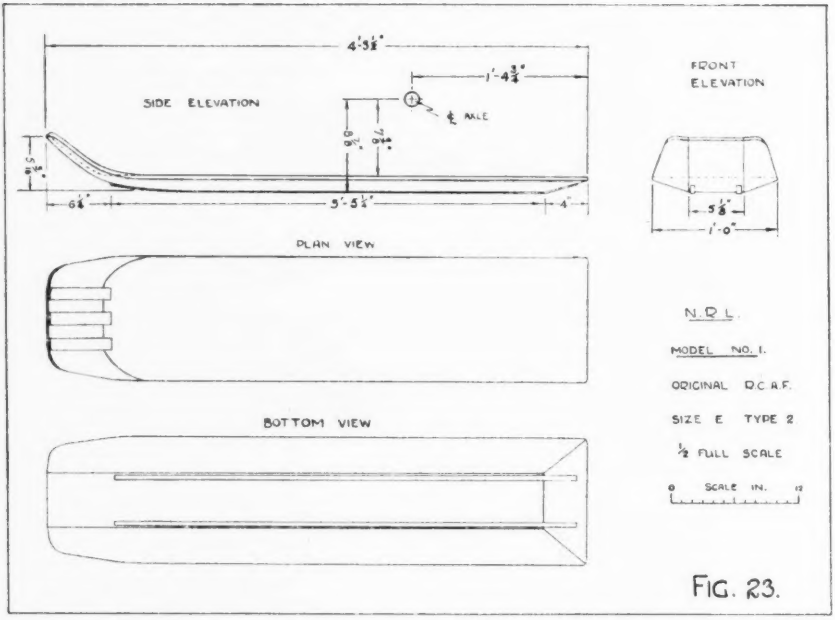

4'-3½"
1'-4¾"
SIDE ELEVATION
⅛ AXLE
6¼"
3'-5½"
4"
PLAN VIEW
BOTTOM VIEW
FRONT ELEVATION
5⅛"
1'-0"
N.R.L.
MODEL NO. 1.
ORIGINAL D.C.A.F.
SIZE E TYPE 2
½ FULL SCALE
0 SCALE IN. 12

FIG. 23.

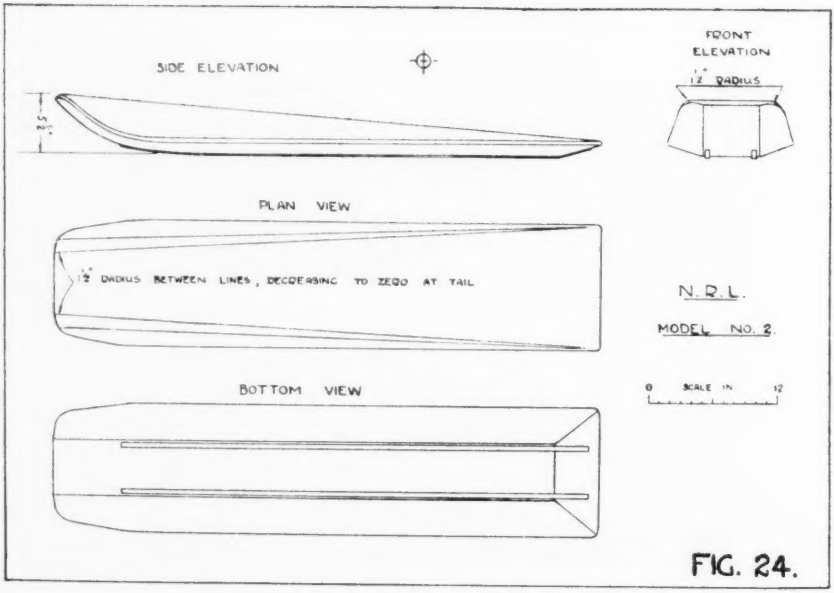

SIDE ELEVATION
PLAN VIEW
½" RADIUS BETWEEN LINES, DECREASING TO ZERO AT TAIL
BOTTOM VIEW
FRONT ELEVATION
1" RADIUS
N.R.L.
MODEL NO. 2.
0 SCALE IN. 12

FIG. 24.

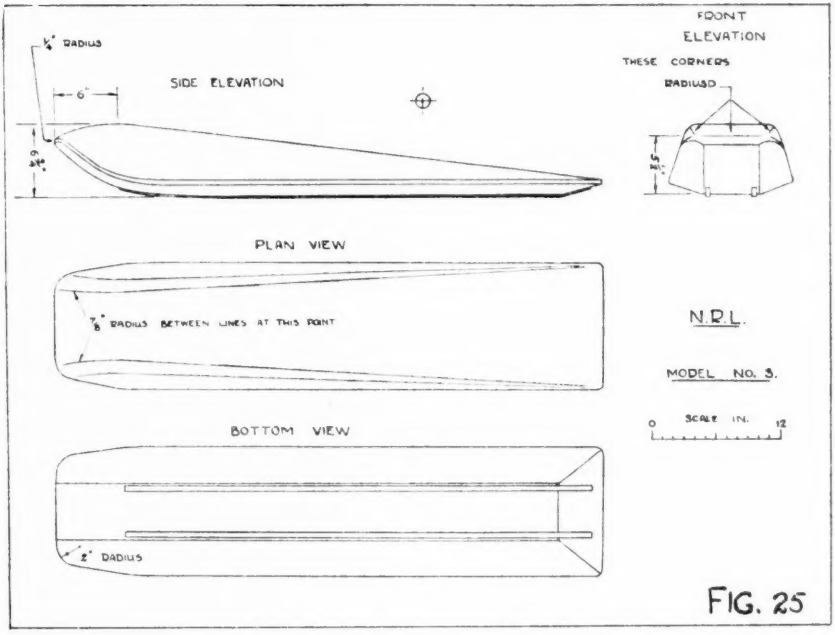

1/4" RADIUS
SIDE ELEVATION
6"
2 1/2"
FRONT ELEVATION
THESE CORNERS RADIUSED
2 1/2"
PLAN VIEW
3/8" RADIUS BETWEEN LINES AT THIS POINT
BOTTOM VIEW
2" RADIUS
N.R.L.
MODEL NO. 3.
0 SCALE IN. 12

FIG. 25

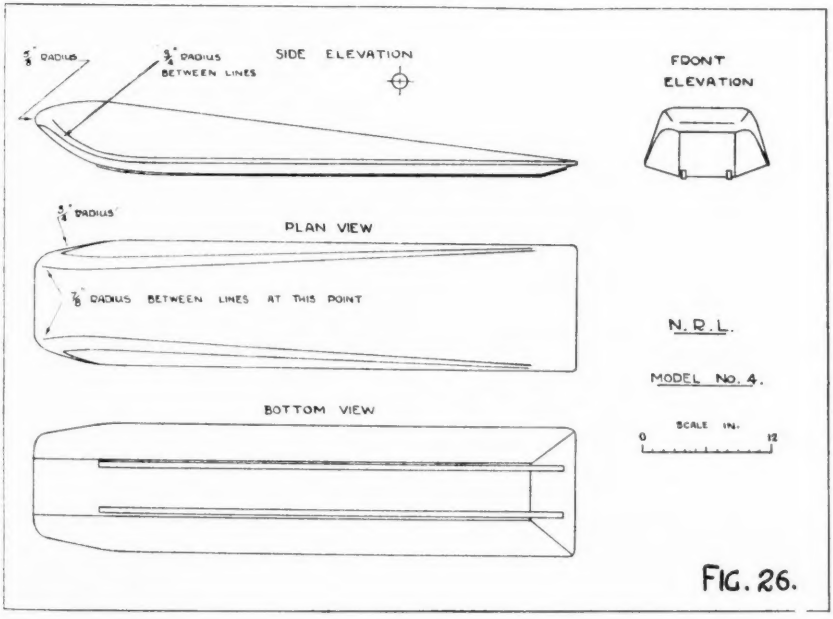

3/8" RADIUS
3/4" RADIUS BETWEEN LINES
SIDE ELEVATION
FRONT ELEVATION
3/4" RADIUS
PLAN VIEW
3/8" RADIUS BETWEEN LINES AT THIS POINT
BOTTOM VIEW
N.R.L.
MODEL NO. 4.
0 SCALE IN. 12

FIG. 26.

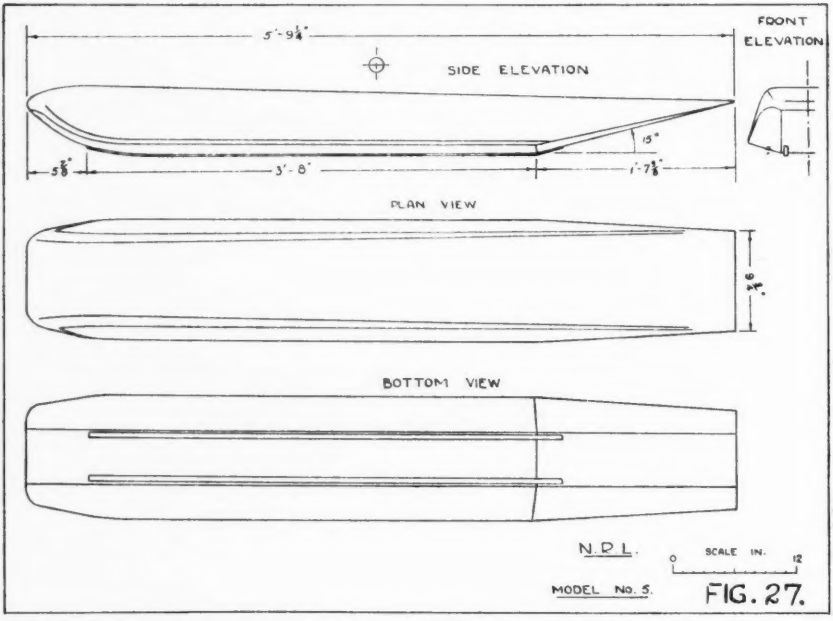

5'-9¼"
SIDE ELEVATION
FRONT ELEVATION
15°
5⅝"
3'-8"
1'-7⅛"
PLAN VIEW
BOTTOM VIEW
N.P.L.
SCALE IN.
0
12
MODEL No. 5.

FIG. 27.

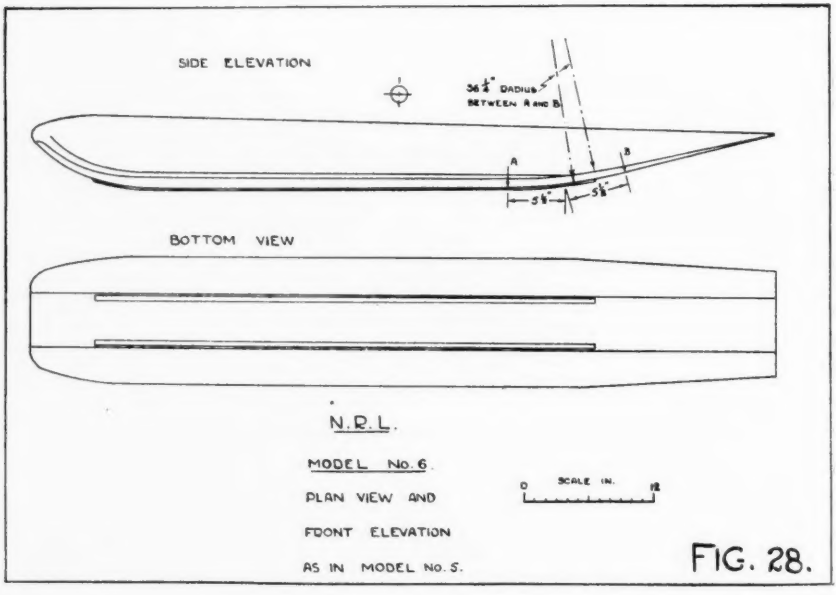

SIDE ELEVATION
36¼" RADIUS BETWEEN A AND B
A
B
5⅛"
5⅛"
BOTTOM VIEW
N.P.L.
MODEL No. 6.
PLAN VIEW AND
FRONT ELEVATION
AS IN MODEL No. 5.
0
SCALE IN.
12

FIG. 28.

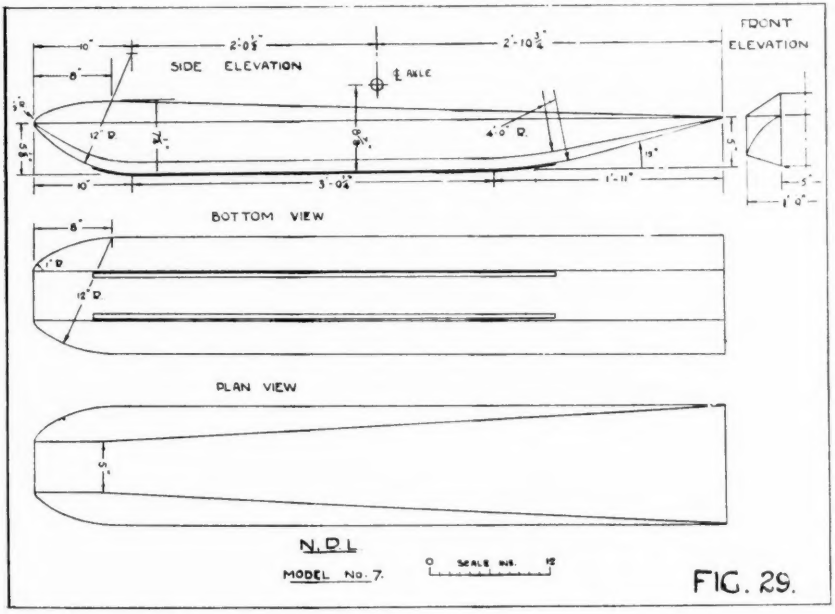

SIDE ELEVATION
FRONT ELEVATION
℄ AXLE
BOTTOM VIEW
PLAN VIEW
N.P.L.
MODEL No. 7.
SCALE INS.

FIG. 29.

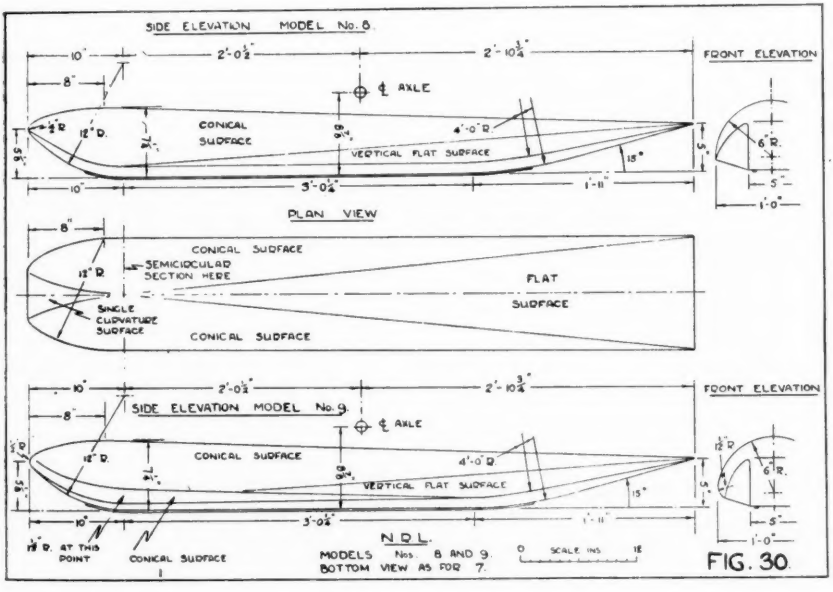

SIDE ELEVATION MODEL No. 8.
FRONT ELEVATION
℄ AXLE
CONICAL SURFACE
VERTICAL FLAT SURFACE
PLAN VIEW
SEMICIRCULAR SECTION HERE
FLAT SURFACE
SINGLE CURVATURE SURFACE
SIDE ELEVATION MODEL No. 9.
AT THIS POINT
N.P.L.
MODELS Nos. 8 AND 9.
BOTTOM VIEW AS FOR 7.
SCALE INS.

FIG. 30.

By comparing the results for model No. 1, the basic type without pedestal, with the full size type with pedestal and neglecting scale effect, the drag of the pedestal is derived. This has been done in Fig. 35, which shows the separate contributions to drag, of ski, pedestal and trimming gear. In the attitude of minimum drag, each seems to contribute approximately one-third of the total drag. At other incidences, the drag of the ski itself predominates.

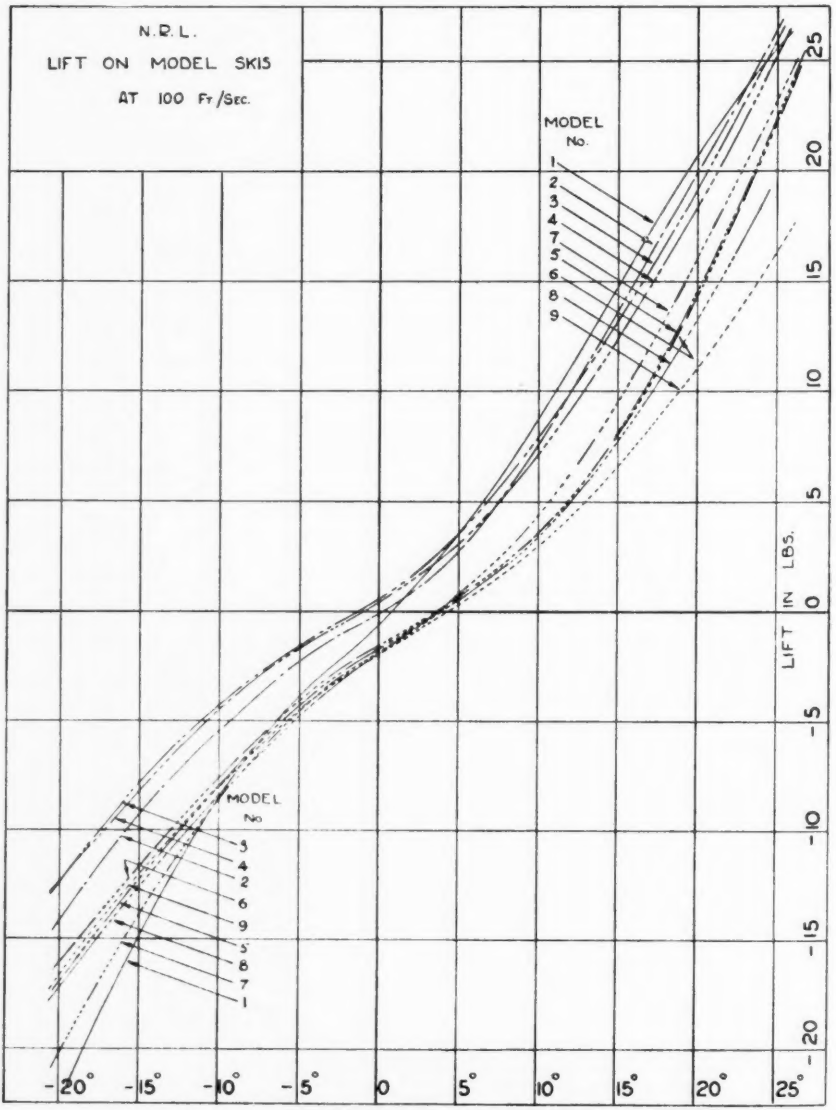


FIG. 31.

Model No. 2 represents the simplest type of faired ski, obtained by cowling model No. 1 with flat sheets on straight generators from the ski front to the back. This resulted in a reduction of approximately 60 per cent. in minimum drag and a perceptible reduction in the slope of the moment curve.

Model No. 3 was obtained by adding a single curvature back to the ski, with the point of maximum depth near the front end (Fig. 25). Further improvements in drag and moment resulted.

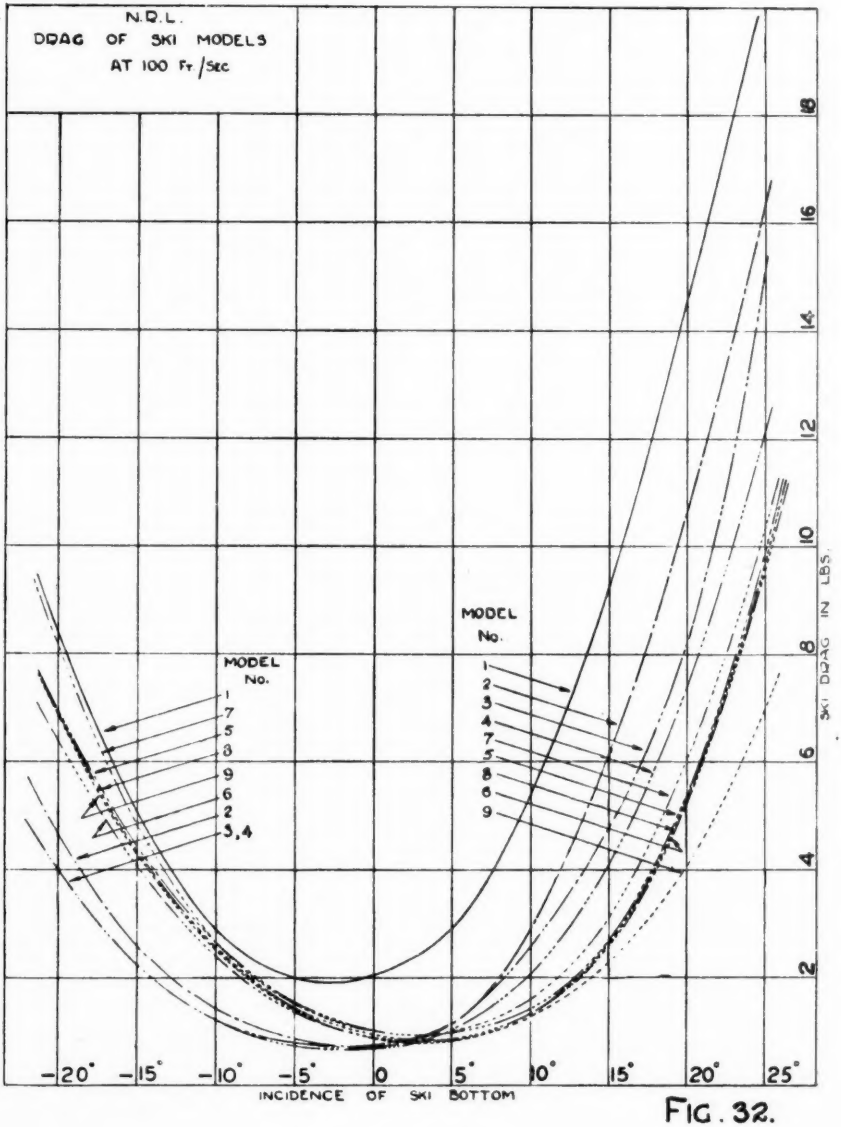


FIG. 32.

Model No. 4 resulted from rounding off the sharp edges at the front of No. 3. As was to be expected, this was found to reduce air resistance at positive and negative incidences, with beneficial effects on the moment curve.

In model No. 5 the front was unaltered but the rear of the ski was lifted in order to lengthen the body of the ski (Fig. 27). This had a very marked beneficial effect on the moments at large angles of incidence (positive and negative), but slightly increased the minimum drag which now occurred at an incidence of $+3^\circ$ instead of the $-2\frac{1}{2}^\circ$ for the basic model.

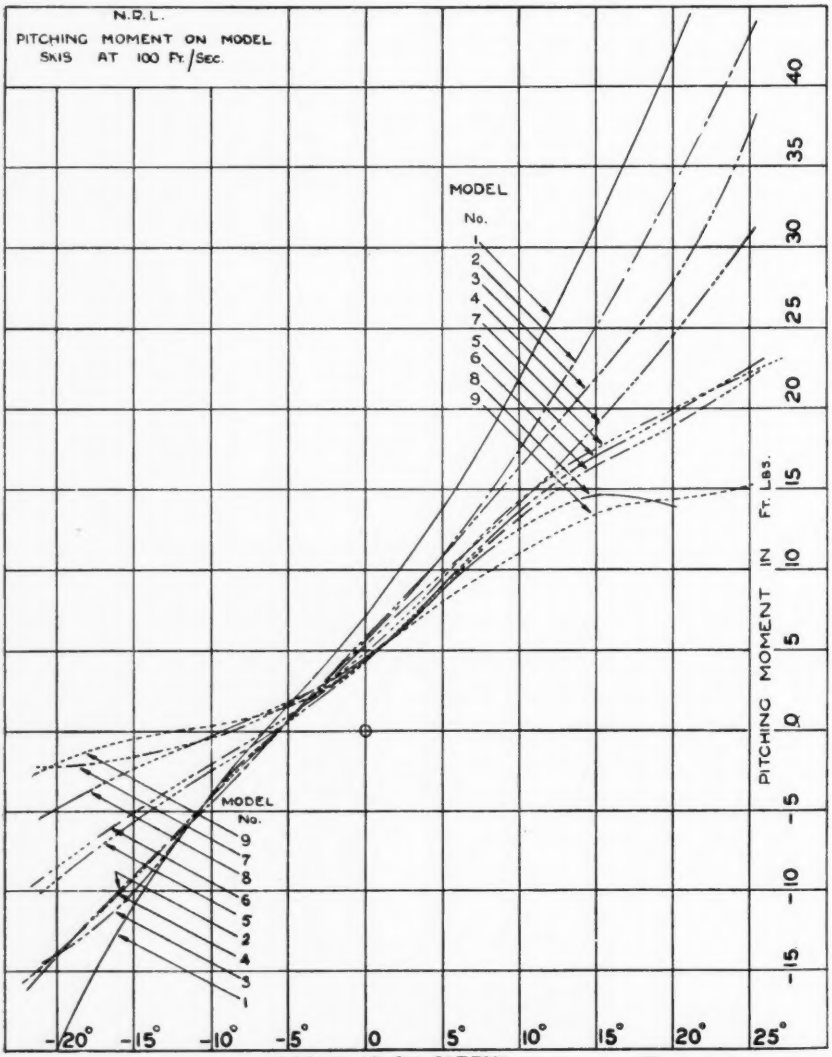


FIG. 33.

Model No. 6 was obtained by rounding the sharp edge where the lengthened portion of the body met the snow bottom. This gave slight beneficial changes in drag and moment.

In the two foregoing models (5 and 6) the shape of the cowling in conjunction with the lifted rear end of the ski resulted in a narrowing of the width of the ski at the rear which is well shown in Figs. 27 and 28. It was felt that, if full width could be maintained, an improved moment curve would result.

Model No. 7 was radically different from the previous models except for the snow bottom and the lengthened portion of the ski. The cowling was quite altered and was composed of five separate single curvature sheets (see Fig. 29). The drag of this model was slightly greater than that of model No. 6, and the moments at positive incidences were also slightly increased, but at negative

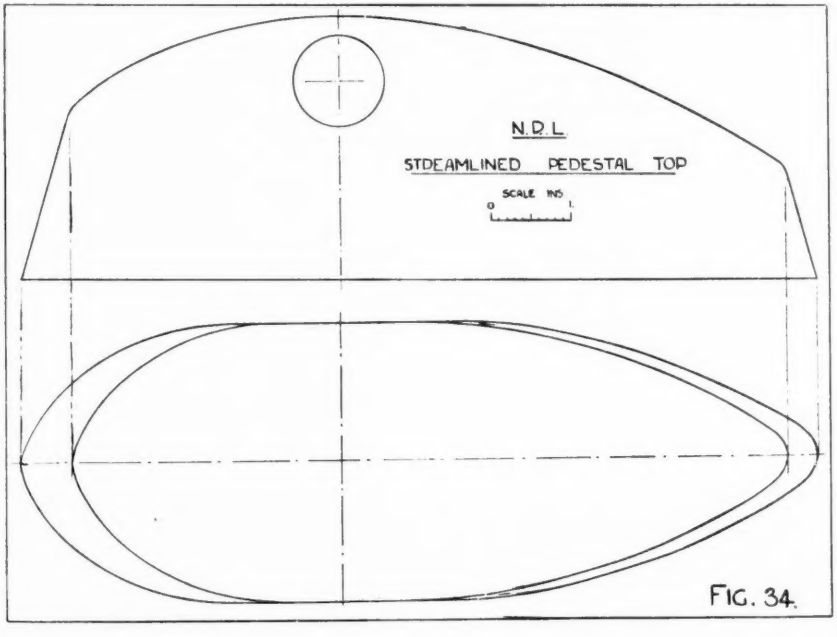


FIG. 34.

incidences substantial reductions in the moment appeared, the slope of the moment curve becoming zero at $-20°$. The effectiveness of the lengthened portion of the body at negative incidences is to be expected from its shape which is also obviously less effective at positive incidences.

Model No. 8 was obtained by planing down No. 7 to a semi-circular section at the point of maximum depth, running it into conical surfaces, extending to the two corners at the rear of the ski. The model is shown at the top of Fig. 30. The tests showed slight drag reductions on the previous model and an increase in negative moments at large negative incidences, but a very materially improved moment curve at incidences above $+10°$.

Model No. 9, the final type, was obtained by rounding off the sharp edges at the front of No. 8 and continuing the radius all along the sides or chines as shown at the bottom of Fig. 30. This resulted in further improvements in drag and quite considerable reductions in pitching moment at both positive and negative incidences.

Fig. 33 shows clearly the very large reduction in pitching moments between model No. 1 and the final model No. 9.

From Fig. 31 it is seen that the lift coefficients are very similar for all models, especially if plotted with the no-lift angle as zero. The basic model has a steeper slope through the angle of no-lift than any of the others. The modified

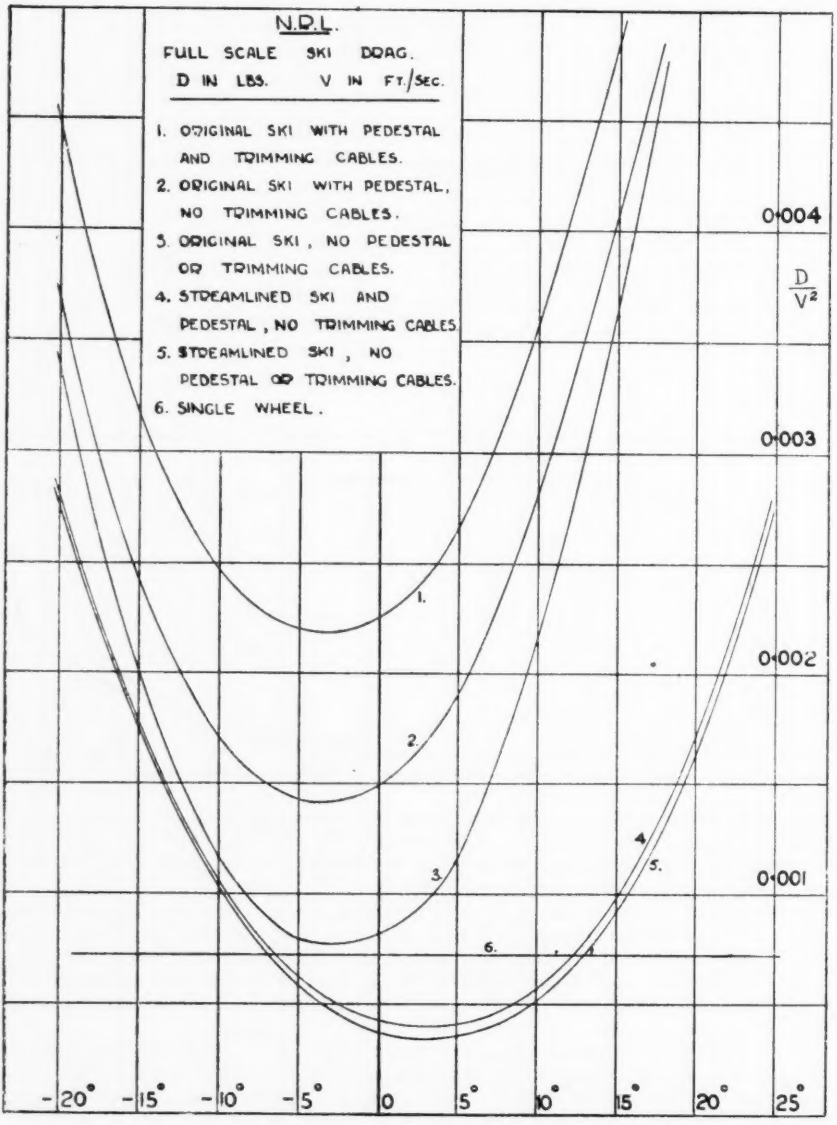


FIG. 35

models fall into two groups—unlengthened and lengthened models—due to the change in the no-lift angle for the latter group. As in the full size tests, the lift is unimportant from a practical point of view.

The same grouping of the modified models is evident in the drag curves of Fig. 32, the lengthened models falling into one group and the earlier unlengthened models forming another group. It is noteworthy that:—

(1) Reductions in minimum drag over and above that obtained by the simplest of cowlings are not very significant.

(2) The effect of streamlining in reducing drag has been considerable at incidences other than that of minimum drag.

Having arrived at a satisfactory design, it was necessary to consider the pedestal. In view of the shape of the ski, it was evident that the major portion of the pedestal would be enclosed by the fairing of the ski and it was therefore only necessary to consider the streamlining of the exposed pedestal top. Fig. 34 is a drawing of the pedestal cowling proposed, which is sufficient to accommodate the existing type of pedestal.

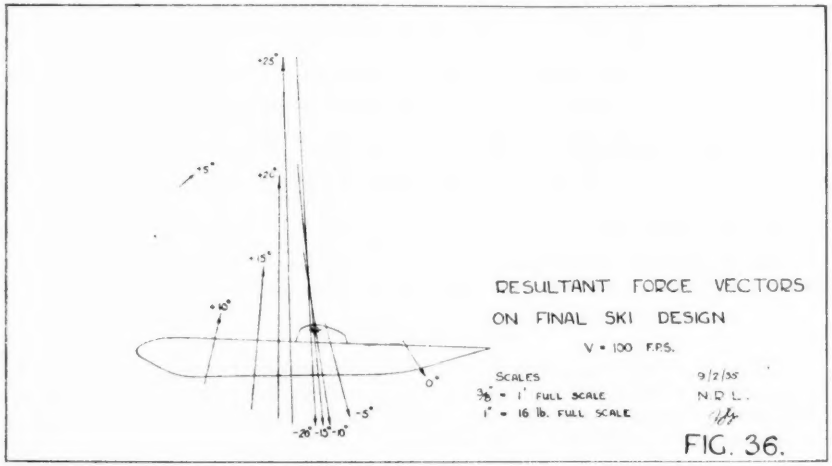


FIG. 36.

Lift, drag and pitching moment about the axle centre line were measured as before.

Fig. 35 contains drag curves, calculated for full scale, for the final shape of ski both with and without the streamlined pedestal. It will be observed that the pedestal contributes a small addition to the ski drag.

Fig. 36 is a resultant force vector diagram for the final ski. The much improved position of the vectors with respect to the axle is quite obvious in comparison with the original ski (Fig. 15).

Considering the improvement in the pitching moment diagram, it would appear that some form of trimming gear enclosed within the ski cowling could be utilised in place of the external high resistance trimming cables. If this is possible, then the improvements in drag are considerably augmented.

Fig. 35 gives an indication of the total saving in drag with internal trimming gear. Comparing curves 1 and 4 shows that the minimum drag of the ski installation has been reduced by as much as 82 per cent.

Comparing the final ski drag with a wheel, it is seen that the drag of the ski is only some 57 per cent. of that of the wheel so that performance should be improved when changing from wheels to skis of this type.

Conclusions

The tests on the full size skis indicate that there is opportunity for considerable aerodynamic improvement in existing skis by reducing the large air resistance and by reduction of the slope of the pitching moment curve. In addition to the direct improvement due to the latter, an indirect improvement results from the possibility of using some form of enclosed trimming gear, thereby saving the considerable air resistance of exposed gear.

These conclusions have been justified by the results of the second part of the tests in which a new design of ski has been developed which allows an 82 per cent. reduction in the drag of the ski installation coupled with very considerably improved pitching moment characteristics.

The tests indicated generally that the most important features in reducing the unstable pitching moment are :—

(1) A smooth front end free from sharp edges.
(2) A lengthened body ending in a horizontal knife edge as wide as possible.

It was noticed that sharp edges at the front not only added to moment and resistance, but were responsible for violent lateral oscillation of the model.

Very considerable improvement is to be expected for the Ontario Provincial ski if the very sharp edges at the front end could be given a generous radius. This ski was prone to large lateral oscillation at positive incidences.

Further Developments

The Department of National Defence is modifying a pair of full size skis to the improved design for full-scale tests on the Hawker " Audax."

Acknowledgments

The authors are grateful to the Department of National Defence, Aeronautical Engineering Division, the Ontario Provincial Air Service and the Millar Mineral Exploration Company for the loan of equipment which made possible these investigations.

References

1. N.R.L. Report No. PAA–6. " Pitching Moments on Aircraft Skis." J. J. Green.
2. N.R.L. Report No. PAA–13. " Wind Tunnel Tests on the Trimming of Aircraft Skis." J. J. Green.

Appendix

Recommendations with regard to the Design of Winter Landing Gear incorporating the Improved Design of Ski

In order to realise all the potential advantages (aerodynamic and otherwise) offered by the streamlined ski, the following recommendations are made :—

1. The ski pedestal should be of the rigid type and not of the shock absorbing (oildraulic) type.
2. The ski with its rigid pedestal should be used in conjunction with a specially designed ski undercarriage instead of attempting to fit the ski to an existing wheel undercarriage.

3. If a special ski undercarriage is not possible, the wheel undercarriage shock absorbing unit should be capable of a double range adjustment—one range for use with wheels and the other range for use when wheels are replaced by skis (the ski pedestal being of the rigid type).
4. The ski trimming gear should be enclosed in the ski itself and should operate on the axle. External trimming cables, due to their very high resistance, should be avoided.

The arguments on which these recommendations are based are given below:—

Advantages of a Rigid Pedestal over a Flexible Oildraulic Pedestal

1. With a rigid pedestal, it is possible to completely seal the ski cowling. With a flexible pedestal, it is difficult or impossible to seal against the entry of snow, water and slush.
2. A rigid pedestal can be more effectively streamlined than the more complex flexible pedestal.
3. With a rigid pedestal, the problem of internal trimming can be solved easily. In the case of a flexible pedestal, this problem is very difficult.

Arguments in Favour of a Special Ski Undercarriage

1. The majority of machines operating in the north country use either floats or skis, practically never do they use wheels, landing fields being absent. It is therefore most logical to use skis on an undercarriage especially designed for them. At present, the practice is to use the wheel undercarriage which has certain inherent disadvantages when carrying skis.
2. When changing from wheels to skis, extra shock absorbing must be provided to allow for the absence of the tyre. At the present time, this is provided by a flexible pedestal. In designing a special ski undercarriage, this problem can be dealt with so that the extra shock absorbing qualities can be provided in the undercarriage and a rigid pedestal used in the ski.
3. Permits the axle to be lowered right down to the top of the ski cowling (by extending the length of the undercarriage members, the attitude of the machine on the ground being unaltered). This results in only the bare minimum of pedestal being exposed outside the ski cowling and consequently a reduced air resistance.
4. On some machines, when changing from wheels to skis, the brake drum has to be left on the axle. This would require a large and awkward cowling to streamline it. This question does not appear if a special ski undercarriage is designed.
5. Permits the undercarriage to be designed to take the loads peculiar to skis. If internal trimming gear is used, the axle will have to carry the trimming loads in torsion. The loads arising from efforts to " unstick " a ski when the other ski is free can be more effectively dealt with.
6. A saving in weight can be made by using a lighter rigid pedestal and a larger capacity shock absorbing unit in the undercarriage. With the present arrangement of two shock absorbers, one in the undercarriage and one in the ski pedestal, weight is added.

General

The provision of a solid pedestal and a special undercarriage designed for skis enables full advantage to be taken of the streamlined ski. By the ability to use internal trimming and by keeping that portion of the pedestal which protrudes

from the ski cowling to the smallest possible dimensions, the air resistance of the ski can be reduced to less than one-fifth that of the original type of ski with its exposed trimming cables. The resistance of the ski is then only 57 per cent. of that of a wheel for the same aeroplane.

Double-Range Shock-Absorbing Unit

If it is not possible to provide a separate undercarriage for skis, it is recommended that the shock absorbing unit of the wheel undercarriage be provided with a double range adjustment, one for wheels and one (more flexible) for skis. In this way, a rigid ski pedestal with its attendant advantages is retained.

FLYING-BOATS AND THEIR POSSIBLE DEVELOPMENTS

BY

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The Author endeavours to indicate briefly the growth of flying-boats from their inception to the present day and to forecast their probable line of development in the future. It is shown that our present achievement has been arrived at after the comparatively short period of twenty-five years and an attempt has been made to indicate the type of flying-boat which might normally be expected to mature within the next decade.

The water characteristics of a present-day hull are discussed and typical curves are included giving the resistance, attitude and the effect of applied moment for a flying-boat of approximately 40,000lb., all-up weight.

Before proceeding to a detailed investigation into a particular case of a flying-boat of the future, the Author briefly describes the progress which has been made with regard to the engines and compares the relative advantages of the compression-ignition engine and the petrol engine. Reasons are given why the petrol engine still tends to retain its supremacy.

For the future development the Author has taken the particular case of a flying-boat of 300,000lb. all-up weight and has attempted to analyse the probable structure weight of such an aircraft and what could reasonably be expected in the way of pay load and performance. The general conclusions are that the construction of such a boat would be possible, its structure weight by means of an increased wing loading could be maintained at the present-day figure and that its performance would materially increase.

The subject of this paper is an extremely important one inasmuch as it is more than probable that the airways of the future, particularly as far as this country is concerned, will be largely over water. Equally important is the development from the naval standpoint, as the flying-boat is beginning to assume duties normally assigned to naval vessels. From the earliest days of flying, designers have been interested in the problem of building aircraft which would alight on or take-off from the water, and although the development of the marine aircraft may not have been quite so spectacular as has been the case in the land type, yet steady progress has been maintained for many years past. In fact, it is more than probable that the future of large aeroplanes will be largely bound up with the development of the flying-boat.

There are, in general, two distinct types of aircraft which operate from water, namely, the flying-boat or, as it is officially termed, the boat seaplane, and the float seaplane. The essential difference between these two types of aircraft is that the float seaplane uses its floats almost entirely for the purpose of taking-off from or alighting on the water. Occasionally the interior of the floats is used to store equipment, and sometimes fuel, as was the case in the Schneider Trophy seaplanes, but normally their chief function is to provide a means for alighting and taking-off purposes. In other respects, the float seaplane is similar to a land machine with the floats nearly replacing the normal land undercarriage. The hull of a flying-boat is, however, used in a similar way to the hull of an ordinary surface vessel and contains the crew, equipment, as well as the military or commercial load.

Figs. 1 and 2 illustrate the differences between the two types. It is evident from these that the flying-boat is a better sea-going aircraft than a float seaplane. The floats of a seaplane are usually made as small as possible consistent with the satisfactory carrying out of their duties, and this results in the reserve buoyancy of the floats being approximately 100-120 per cent. of the total all-up weight. On the other hand, the reserve buoyancy of a flying-boat hull may be as high as 500 per cent. of the all-up weight. Although fulfilling a useful

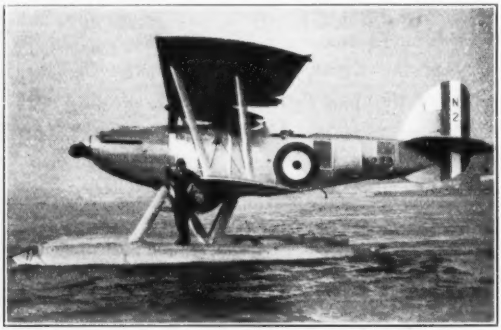

FIG. 1.
"Gurnard" Seaplane.

FIG. 2.
"Calcutta" Flying-boat.

purpose, the seaplane is not capable of the development possible to the flying-boat and it is, therefore, proposed to confine the rest of the paper entirely to the latter type of aircraft.

Historical

Before going into a more detailed consideration of the flying-boat, it may be of interest to describe briefly its history and growth. For this purpose, I have obtained some early photographs which are reproduced in Figs. 3 and 3*a*. The earliest seaplane of which I have been able to obtain a photograph is that built by Mr. Gnosspelius and flown by him on Lake Windermere in 1910. It is to be noted that the flotation unit of this monoplane does not correspond with

that previously described, but is a sort of combination of the two, comprising one large central float. As far as I can ascertain, this was either the first or the second seaplane which flew in England. The type has not been proceeded with and has no modern counterpart.

It would appear that the flying-boat proper first made its appearance in America approximately during the period 1911-12. A flying-boat was produced and flown in England shortly before the war and was used during the early part of the war. It was quite a small aircraft, and as will be seen from Fig. 4 it approximates to the types in use to-day. The first really successful large flying-boat was probably produced by the Curtiss Company of America. This was, undoubtedly, the predecessor of the Porte boats which were built in considerable

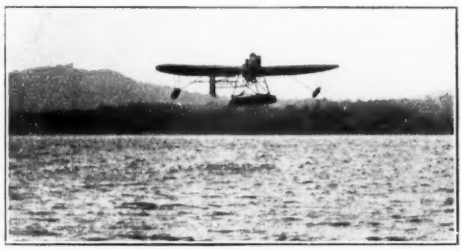

FIG. 3.
Single Float Seaplane (Gnosspelius).

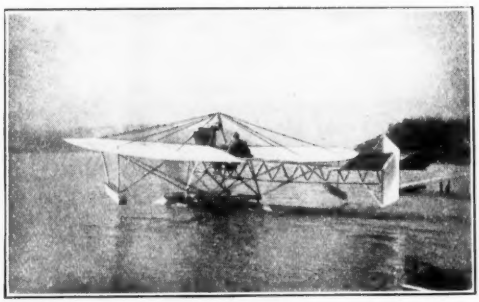

FIG. 3*a*.
Single Float Seaplane (Gnosspelius).

quantity in this country during the latter part of the war. Fig. 5 shows one of these boats, which is the well-known F.5 type. They did a large amount of useful work in the North Sea during the war, an account of which has been admirably written up by flying officers stationed at Yarmouth in a book called "The Story of a North Sea Air Station," by Snowden Gamble.

These early boats were almost entirely constructed of wood, metal being used only for the fittings. The hulls were built on similar lines to those in use for ordinary boat-building, the external sheeting usually being two skins of mahogany, the top sides of three-ply and with longitudinal members of rock elm. Wood, also, was used almost exclusively for the wings, the main spars being of spruce with ribs either of spruce or three-ply, fabric covered. The engines were mounted between the wings on ash bearers which were built on to

the wooden interplane struts. The F.5 type machines were, in the latter stage, equipped with two Rolls-Royce " Eagle " engines, each of 360 b.h.p. The all-up weight of the boat was in the neighbourhood of 12,500lb. For some time after the war little progress was made in the design of marine aircraft, and the F.5 type was still being used both in England and abroad until approximately 1924-1925, when it was replaced in the British service by a smaller type designed and built by Vickers-Supermarine.

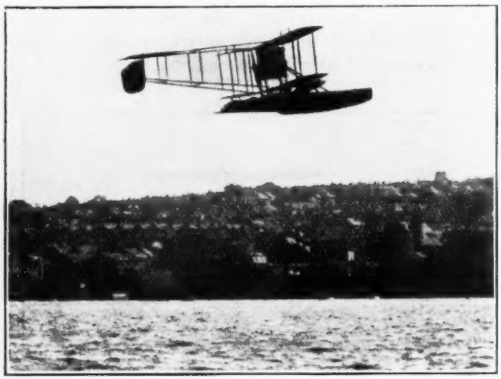

FIG. 4.
Sopwith " Bat " Boat.

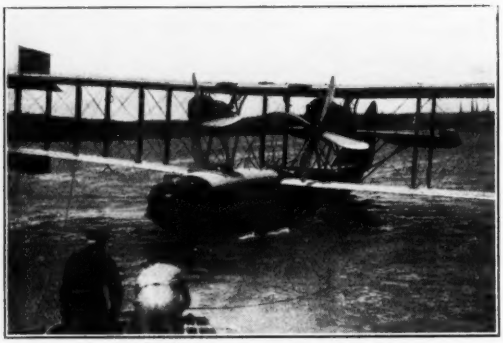

FIG. 5.
F.5 Standard Flying-boat.

In 1925 attention was directed to the possibility of producing flying-boats with hulls constructed in metal, and Short Brothers of Rochester were entrusted with the design of a suitable hull for the standard F.5 boat. Fig. 6 shows the completed hull. The type of construction adopted proved so efficient that in England the wooden hulls were rapidly superseded by the newer method and became a thing of the past. These early hulls were constructed entirely of duralumin—the well-known aluminium-copper alloy. Considerable trouble was at first experienced due to the corrosion of the hulls, as duralumin appeared particularly susceptible to attack from sea water. This was finally overcome by

the use of the anodic oxidisation process combined with the development of duralumin sheets which have a thin skin of pure aluminium on the outer surfaces, the aluminium being incorporated with the duralumin during the ingot stage. Modern hulls, therefore, can be stated to be almost free of corrosion trouble.

Concurrently with the development of metal hulls metal superstructures were evolved, and at the present time practically all flying-boats are of metal construction apart from the wing covering, although the latest American practice is, also, to metal-cover the wings.

No real attempt was made to use flying-boats commercially until a company operated a Supermarine " Swan " between Southampton and the Channel Islands. Later Imperial Airways ran the " Calcutta " on this service in 1928 to obtain experience in the operation of flying-boats. The " Calcuttas " were then transferred to the Mediterranean division of Imperial Airways Empire Services, where

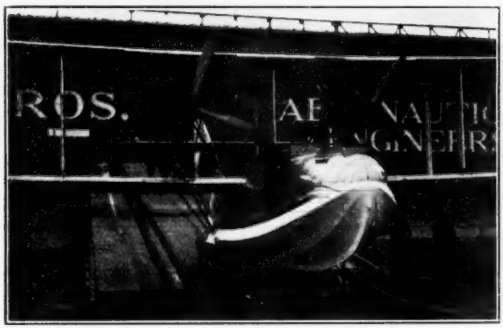

FIG. 6.
F.5 Metal Hull.

they continued to give excellent service until replaced in 1931 by the more modern four-engined " Scipio " class. The " Calcuttas " are still doing useful work although practically obsolete from a design point of view. Figs. 7 and 7*a* illustrate a boat of the " Scipio " type.

Design Considerations

Sufficient has been said regarding the growth of flying-boats from the early days, and it is now proposed briefly to describe the modern flying-boat hull from its various aspects. The characteristics which concern us most are its hydrodynamical properties. A hull designed to meet the required water performance has a beam of hull which is inadequate to provide the necessary stability. In fact, the hull of a flying-boat by itself has a negative metacentric height and, therefore, when at rest on the water the boat is, laterally, unstable. To provide the stability required, it is essential that some form of auxiliary means be adopted. Three well-known ways of obtaining this lateral stability are:—

(1) By means of small stabilising floats placed well out towards the wing tips.
(2) By means of sponsons or stub-wings grown out from the side of the hull.
(3) By using twin hulls.

In this country, the general practice has been to use the small stabilising floats and it must be stated that, although this method at first sight appears to

be rather fragile, no very serious consequences have arisen as a result of adopting this method of obtaining lateral stability. Wing-tip floats have also been used both in France and America, although some of the later boats in these countries have been fitted with sponsons. The sponson form of stabilisation was developed and, until recently, used almost exclusively by the famous Dornier firm in Germany. The twin-hull system has been used and developed almost entirely in Italy and, as my readers are probably aware, the famous flight across the North Atlantic carried out by General Balbo was made on boats stabilised in this manner.

FIG. 7.
"Scipio" in Flight.

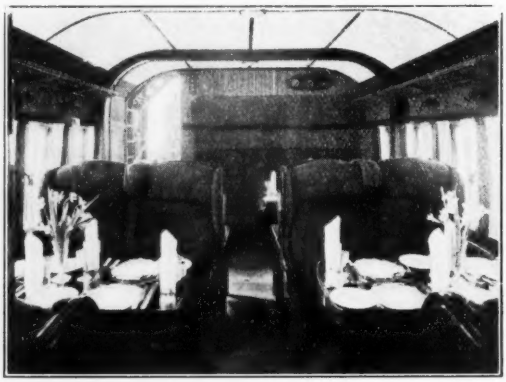

FIG. 7a.
Cabin of "Scipio."

It will be seen, therefore, that there is no general method in use at the moment for providing the requisite lateral stability. Each method has its advantages and disadvantages, and it is impossible to predict which method will finally prove itself to be the best. In our opinion, however, the wing-tip float is the best all-round compromise as it is lighter, causes less interference with the hull during take-off, and its parasitic drag is less than the alternative methods. Fig. 8 is typical of the three distinct types of lateral stabilisation. The boats

with which I am best acquainted are all stabilised by wing-tip floats and, hence, the hulls described in this paper are all of this type.

The under-water surface of a flying-boat hull consists, in general, of a comparatively large fore-body with the main step situated just aft of the horizontal centre of gravity, and a rather fine after-body of approximately the same length as the fore-body. The after-body, in some cases, finishes at a second step or alternatively tapers off to a point. The large fore-body planing surface and the rather fine after-body is required in order that the bow may be lifted to the surface at the lowest possible speed. This means that the fore-body will be lifted faster than the after-body, the hull being rotated about its lateral axis to the required angle in order that the wings may meet the air flow at an incidence angle of approximately 14-16 degrees during the latter portion of the take-off run.

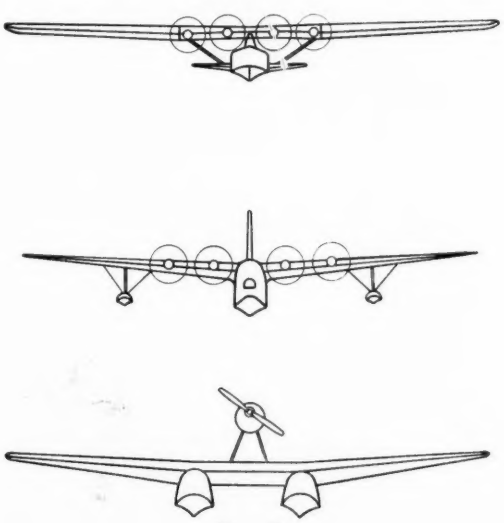

FIG. 8.

Forms of Lateral Stabilisation.

The determination of the shape of the fore- and after-body of a hull is determined from model tests in an ordinary seaplane testing tank. Certain general principles are used for guidance, but it is impossible to lay down, with any certainty, the lines of a hull for any particular aircraft, as the exact position of the steps depends both upon the amount of engine thrust available and the vertical position of the centre of gravity. Fig. 9 illustrates the general lines of a typical hull, together with the data relating to its thrust line and centre of gravity. The procedure adopted for the carrying out of model tests is well known in this Institution, so there is no need to describe in detail the methods employed. In predicting from models test to full scale it is usual to ignore the effect of skin friction and to assume that the whole of the resistance is due o wave-making. This assumption, therefore, errs on the side of safety. Fig. 10 shows a typical set of resistance and attitude curves from the flying-boat hull previously shown. This flying-boat had a total all-up weight of 40,000lb. and a take-off speed from the water of about 60 knots. From the curves it will be seen that the resistance increases at approximately a uniform rate from zero forward speed to 22 knots, the resistance being a maximum at this speed and of

the order of 7,000lb. Above 22 knots the resistance decreases in a uniform manner up to approximately take-off speed.

As explained previously, the large fore-body of the hull has rotated the machine about the lateral axis. This is shown by curve of running angle against speed. From this curve it will be seen that the running angle increases rapidly up to a speed of about 25 knots and thereafter increases more slowly, reaching the maximum between 45-50 knots. After this, if left on its own, the boat

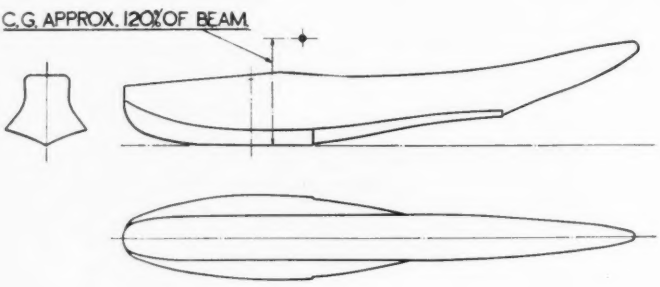

FIG. 9.
Lines of Typical Hull.

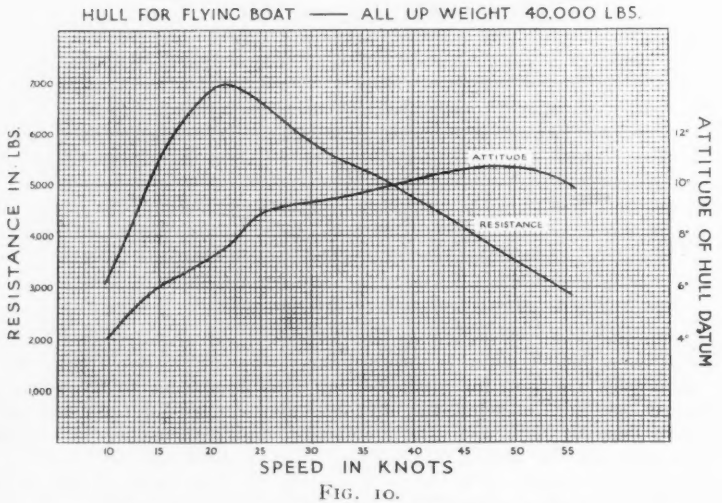

FIG. 10.
Resistance-attitude Curve of Flying-boat Hull.

would trim forward. At this speed, however, the pilot is able to control the boat longitudinally and alter the angle through a small range by use of the tail elevator.

The curve of resistance is for the hull alone, and is that due entirely to the water forces. In addition to the water forces, there is also the air resistance to be overcome by the propeller thrust. The water resistance for most normal boats is, however, by far the most important, and consequently the acceleration is least at a forward speed of from 20 to 30 knots corresponding to the hump

speed. These curves have been corrected for any air lift the planes may be giving at the particular speeds.

In addition to test to obtain the resistance and attitude curves of a flying-boat hull, it is usual to test at a comparativley high forward speed the ability of the hull to be altered in angle by means of applied moments. This is to ensure that the pilot shall have some control over the longitudinal running angle of the boat just prior to take-off speed.

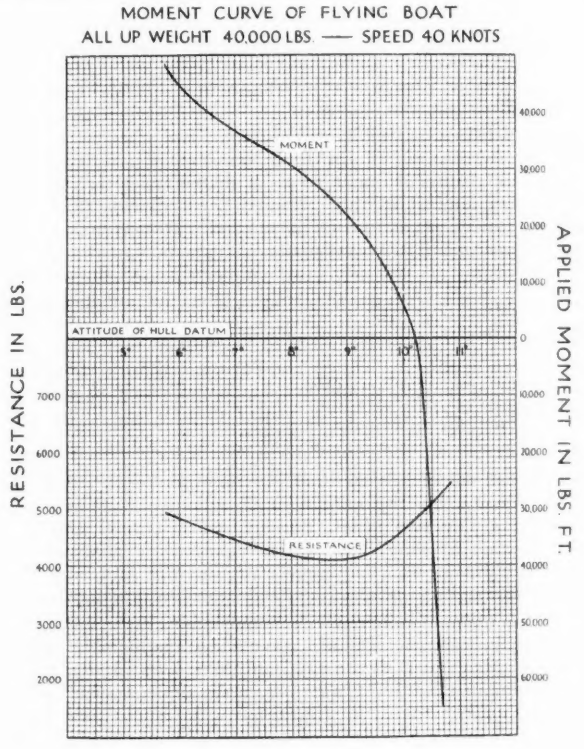

FIG. 11.
Applied Moment Curve.

In order to make this short description of the tank tests complete, the results of a test on a model of the hull previously described, when running at a forward speed of 40 knots, are shown in Fig. 11. This curve shows that an applied moment of 30,000 ft. lb. alters the running angle from 10 degrees to 8 degrees and it also shows that the same moment applied in the opposite sense will only move the boat from 10-10¼ degrees. This is a normal type of moment curve and illustrates that it is comparatively easy to trim the boat forward and difficult to trim it aft. This is done deliberately in order that the full-size boat may not be accidentally pulled into the air at its stalling speed, with the danger of it stalling and dropping a wing and damaging itself during take-off. By trimming the boat forward, it will be noticed that the resistance can be decreased some 300 or 400lb., and although the boat may run a greater distance on the water, the time to take-off will, if anything, be less. This trimming forward is a safe

manœuvre inasmuch as when the boat does leave the water it will definitely have attained a flying speed well beyond the stalling speed, and there is no danger of the boat's accidentally stalling.

In addition to the above tests, investigations are also made into the longitudinal stability of a boat when planing over the water at high speed. The question of the longitudinal dynamic stability of a flying-boat is a very complex subject, and although a considerable amount of mathematical analysis has been done, it is impossible, at the moment, to predict the stability characteristics of any flying-boat hull from theoretical considerations only. Recourse has, therefore, to be made to tests on a testing tank, and if instability occurs on the model it is cured by "trial and error." From my own experience, after many years of intensive tank work, it has become clear that when a model of a flying-boat hull has been completely tested and cured of any instability troubles, then it can be reasonably expected that no trouble will occur in full size.

The foregoing description of the main tests carried out in the tank on the characteristics of hull forms is included as a matter of interest to illustrate that the procedure is very similar to that adopted for ordinary ship forms, although with hulls, perhaps more investigation is needed. Research is continually being carried out on hull forms, but I would not venture to say that we are anywhere near approaching finality, although the modern type of flying-boat hull is, undoubtedly, very efficient for its purpose. This part of the subject has only been treated very briefly in order to give a general idea of the present position of flying-boat design, but I chiefly want to interest you in the possible developments that we can normally expect in the future. Before, however, proceeding with the future development it would not be out of place to discourse for a few minutes on the position as regards the power unit.

Engine Development

The development of the flying-boat, in common with other aircraft types, has been made possible by the considerable advance made in recent years in aero engine design. The two types, namely, water-cooled and air-cooled, have progressed almost side by side, but of late years there appears to be a definite leaning towards the air-cooled type largely on account of its simplicity and ease of maintenance. Succeeding development has now brought us to engines developing roughly about 1,000 b.h.p. with a remarkable horse-power to dry-weight ratio of about 1.25lb. Several factors have been responsible for this progress, the chief of which are:—(*a*) the normal improvement in design and materials, (*b*) the improvement in manufacturing processes, and (*c*) the use of high octane value fuels. The improvement in the quality of fuel used has had a very important bearing on the development of engines as it has enabled the compression ratio to be increased, resulting in a higher mean effective pressure, increased fuel economy, lower exhaust gas temperature, while at the same time providing immunity from detonation.

The speed of an aircraft for a given horse-power varies approximately inversely as the cube of the relative densities, and the engine makers have, also, by means of superchargers, been able to maintain their ground horse-power up to altitudes of 15,000ft. with the consequent increase in performance. In order to take advantage of this increase in horse-power at altitude and at the same time to obtain the power necessary for take-off, increased boost pressures at ground level for short periods have been permitted. The petrol engine has, therefore, been brought to a high state of perfection, but how much further improvement can be made it is difficult to foresee, but I believe a well-known engine builder is visualising obtaining 40-50 rated horse-power per litre of capacity, as against about 28 rated horse-power per litre obtained at the present time.

A considerable amount of attention has been concentrated on the possibility of using compression-ignition or Diesel engines, using heavy oil, and a large

amount of experimental work has been carried out by the Air Ministry as well as by private firms. The use of such engines by aircraft engineers has obvious attractions as the fuel consumption is extremely low, electrical ignition with its complications is eliminated, there is a reduction in fire risk and a considerable saving in fuel cost. In spite of these advantages the compression-ignition engine has not yet been able to displace the petrol engine, largely because of the tremendous difficulties involved in reducing the weight per horse-power to a comparable ratio. This is largely due to the much higher maximum pressure and the rate of pressure rise which necessitates much heavier engine components for engines of equal power. If, however, the total engine plus fuel weight be taken for a cruising range of, say, 10 hours, then the balance becomes in favour of the compression-ignition engine if cruising range alone is considered.

Although several compression-ignition engines have been built in Germany, America and this country, with quite excellent results, the powers of these engines have been well below those which are being obtained from the petrol engine, and this point also tends to retard their use, as the tendency in modern aircraft is for more and more horse-power. Another point of importance is that the petrol engine, with its additional boost, high octane fuel, etc., obtains a power for take-off which cannot as yet be approached by the c.i. engine, and as the take-off power is most essential with modern aircraft with high wing loadings, this becomes almost a deciding factor. It remains to be seen, however, whether the compression-ignition engine will catch up with its petrol rival; but, at the moment, it seems likely that the petrol engine will retain its supremacy for several years.

When we begin to visualise the future, the position regarding the engines is not so clear. As I have indicated in another part of this paper, no difficulty is seen with our present knowledge in building a flying-boat of 100-200 tons all-up weight, but when we come to consider suitable power units, we are immediately faced with a problem to which, at present, there is no solution. From the point of view of safety in flight, it is not actually necessary to have more than four independent power units, as any modern four-engined aeroplane has an adequate performance, under the worst possible conditions, on three engines. From other considerations it may be desirable to use even six independent units. Using the latter arrangement with a total horse-power required for the projected design I shall discuss later of about 24,000, each engine would need to be about 4,000 b.h.p. A single engine of this power is probably outside the range of any future engine development, and it would probably be necessary to sub-divide this unit into four engines, suitably geared together, the individual engines being of a size that would be the result of normal development. Such an arrangement is a possibility, as the design of a suitable transmission and coupling gear could be developed by the time such an aircraft was built. Other prime movers might be considered and the probable use of steam turbines would, at first sight, appear to be attractive, but the weight of the subsidiary items such as condensers, boilers, etc., would definitely rule out such consideration.

Future Development

The possible future development of flying-boats is an extremely wide subject, and in any estimation that can be made it is necessary to consider many technical aspects of the development. Before going into the technical side of the subject it will be interesting to trace briefly what has been done in the past, and to see whether any conclusion can be drawn with regard to the future.

Taking first the question of the growth of the flying-boat since its inception, can any prediction with regard to the future be made by a study of what has been done before? When talking of the growth in this connection, the point under discussion at the moment is the actual physical size of the flying-boat and

not the number of flying-boats built in any particular year. Fig. 12 shows the probable increase in maximum speed with years; Fig. 13 shows, plotted against

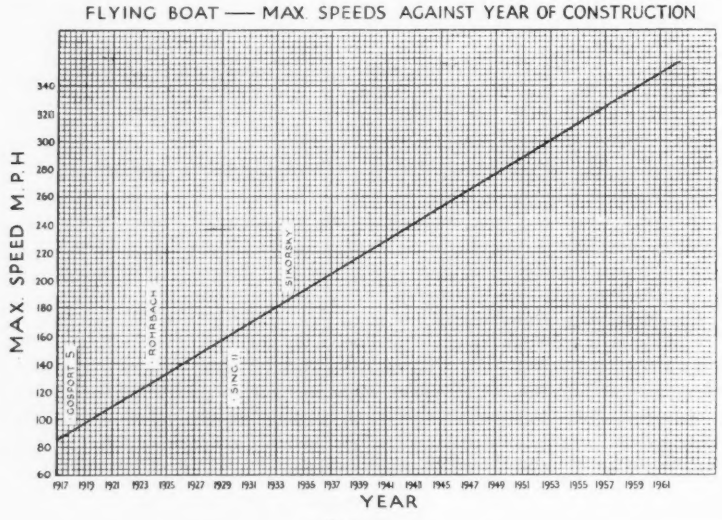

FIG. 12.
Speed Plotted against Years.

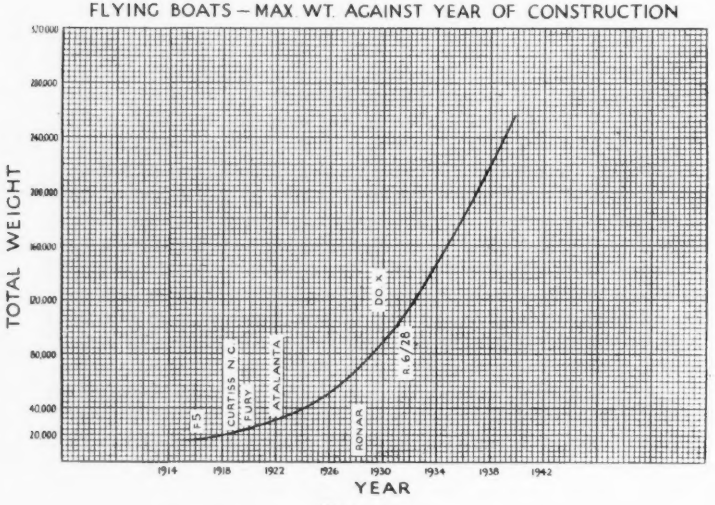

FIG. 13.
All-up Weight Plotted against Year of Construction.

the year of construction, the largest flying-boat built in that year. This curve is extremely interesting. It shows that the growth of the flying-boat in all-up weight is a rapidly increasing quantity with regard to time. It is, of course,

open to question whether this rate of growth can continue, but I think it can be said from the curve drawn through the points, that the exterpolation that I have made beyond the present time is, probably, an under-estimation rather than an over-estimation of what can be produced in the near future.

It is seen that at the present moment it should be possible to start the design and construction of a flying-boat to be produced, say, in the year 1937 or 1938 weighing approximately 220,000lb. This prediction is, of course, based entirely on what has been done in the past, and while this method of prediction is very sound as regards the total all-up weight, it gives no indication whatever how

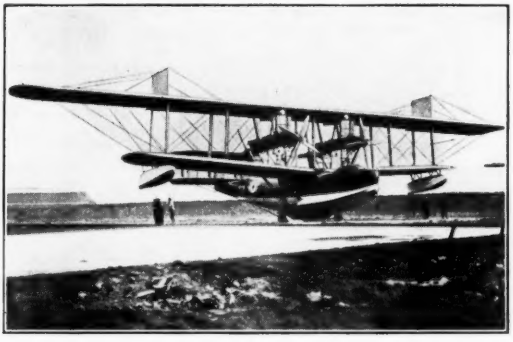

FIG. 14.
"Atalanta"-Fairey.

this total weight is made up and it is conceivable that while you can build a flying-boat weighing 220,000lb., or even more, it is possible that all the weight would be expended in building the hull, wings, etc., and in installing the engines, leaving nothing at all for load or range. It is necessary, therefore, before assuming that the larger boat predicted from the curve of growth is a boat of practical application and not just a theoretical conception, that we attempt to analyse the component parts with particular regard to weight.

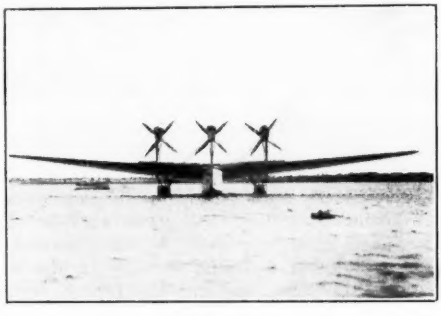

FIG. 15.
"Rohrbach-Romar."

Considering first the question of the hull for boats of varying all-up weight, it is easily proved that the beam of a flying-boat hull varies directly as the cube root of the total weight. Also, within small errors, the fore-body and after-

body planing surfaces vary in the same manner. If, therefore, one can assume that the depth of the hull and the top-side width of the hull are proportional to the beam (this assumption is, in general, a good approximation, but not necessarily strictly true), the surface areas of similar boats are proportional to the ratio of the total weights to the two-thirds power. The weights of similar

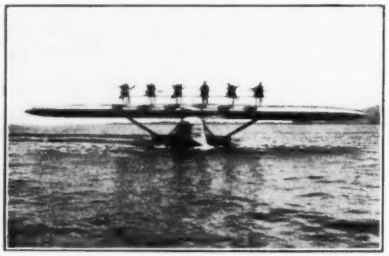

FIG. 16.
Dornier "Do. X."

flying-boat hulls will, therefore, be proportional to the ratio of total weights to the two-thirds power multiplied by some quantity which represents the skin thickness of the hull, when this skin thickness is taken to include any frames or stiffeners.

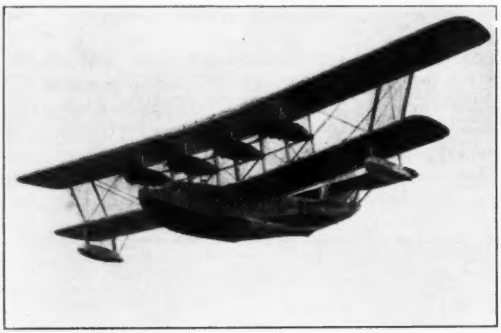

FIG. 17.
"Short" R.6/28.

If one now considers the stresses set up in the skin of the hull due to, say, a special landing case, that is, hitting the water surface at a fine angle, it is easy to arrive at a variation of this quantity which I have called skin thickness for similar hulls. This thickness is found to vary in the ratio of total weight to the two-thirds power; therefore, around the centre section of the hull the weight of the hull will vary as the ratio of the total weights to the four-thirds. This is always assuming that no greater stresses can be developed in the thick-skinned large hull than on the thin-skinned small hull. Actually, of course, a greater skin stress can be developed with the thicker plates; therefore, although theoretical considerations lead to the conclusion that the weight of centre sections of flying-boat hulls varies as the all-up weight to the four-thirds, the actual increase in weight will be less than indicated here for the reason mentioned above.

For the purposes of this paper I propose to assume that it is required to design a flying-boat of, say, 300,000lb. all-up weight, and the remainder of the paper will be an attempt to forecast the weights of the various components and what could be reasonably expected from such a boat in the way of performance and pay load. For the hull there is no doubt that the centre portion will increase in weight slightly less than that given by the ratio of the total weights to the four-thirds power, and this ratio will hold over about half the area of a flying-boat hull surface. The other half of the surface area will probably not need increasing in thickness over the thicknesses existing on present-size hulls where the skin thicknesses are determined more from practical considerations than by any calculated stresses. If the above assumption can be considered reasonable, and I am of the opinion that it is, then it can easily be seen that the weight of the hull for a flying-boat of 300,000lb. weight, will be in the neighbourhood of 13½ per cent. of the total all-up weight, as compared with about 12 per cent. for a boat weighing 60,000lb.

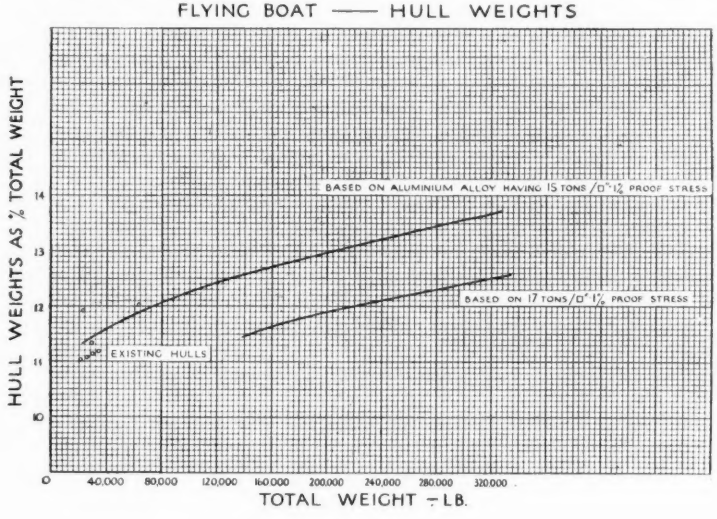

FIG. 18.
Weight of Bare Hull as Percentage of Total All-up Weight.

Fig. 18 shows the percentage weight of a bare hull plotted against the all-up weight for boats of which I have personal knowledge, and while these ranges and weights are limited to an all-up weight of 68,000lb., I am of the opinion that the exterpolation of this curve to heavier boats is not an under-estimation of the hull weight. The weights of existing flying-boat hulls and the exterpolation therefrom are based on the use of aluminium alloy material throughout the construction of the hull, both for skin sheeting and for structural members. This material has a 0.1 per cent. proof stress of 15 tons/sq. in. At the present time it is possible to obtain aluminium alloy with a 0.1 per cent. proof stress of 17 tons per sq. in. having corrosion resisting properties equal to that of the lower strength material. The dotted line in Fig. 18 shows the estimated weights of large flying-boat hulls using this better quality of aluminium alloy. It will be seen that a gain of over 10 per cent. in weight is made by the use of this better quality material. It can, therefore, be stated with some confidence that the weight of a flying-boat hull for a machine weighing 300,000lb. would be in the

neighbourhood of 12½ per cent. of the total weight. In estimating the saving in weight due to the using of better class material account has only been taken of that part of the hull structure whose weight varies as the total weight to the four-thirds power.

Having dealt briefly with the question of hull weights for a machine weighing 300,000lb., the next item which requires serious consideration is that of the wings. For the wings considered it will be assumed that they are of the cantilever type, with the power units mounted in the wings. The fuel is also accommodated in the wings. In the Appendix will be found some theoretical work which has been done on the subject of spar weights for cantilever wings. From this it will be seen that the spar weight is directly proportional to the wing span cubed, to the wing loading, to the density of the material used, and also as a complicated function of the geometrical form of the wings. In addition, it will be seen that the weight is inversely proportional to the amount of allowable stress. For the purpose of this paper an example has been taken where the plan form is assumed

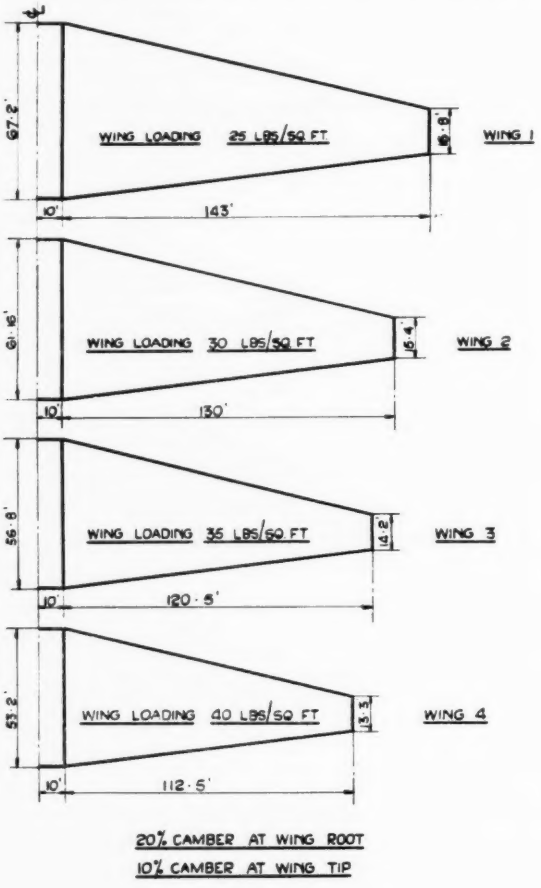

FIG. 19.

Plan Form of Wings for Various Wing Loadings.

to be a straight taper, the chord of the wing at the root being four times the chord of the wing at the wing tips, the depth of the wing being decided by a 20 per cent. camber ratio at the root and a 10 per cent. camber ratio at the tip. Also an aspect ratio of 7 has been used, where the aspect ratio is defined as the span$^2 \div$ area, the span being the total distance from wing tip to wing tip, and the area being total area, including that part of the wing which passes through the body. The body is assumed to have a constant width of twenty feet.

Calculations of weight have been made, using the foregoing wing geometry for wing loadings of 25, 30, 35 and 40lb. per sq. ft. Fig. 19 shows the plan form of these wings to the same scale. A load factor of five is used in all cases. The allowable intensity of stress has been assumed to be 50,000lb. per square inch in tension and 30,000lb. per square inch in compression, and the material used is an aluminium alloy having a relative density of 2.85.

TABLE I.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
WING.	LOADING.	RELIEVING LOAD.	BOOM WEIGHT.	SHEAR WEIGHT.	JOINTS ETC.	SPARS WEIGHT.	EXTRA TO SPARS	TOTAL WINGS.	WEIGHT OF WING Lbs/Ft^2	WINGS % TOTAL WEIGHT.
1.	25 Lbs/ft	8 Lbs/ft	18340.	10,680	5,800.	34,800.	27000.	61,800.	5·15.	20·6%
2.	30 Lbs/ft	8·75 Lbs/ft	16,720.	10,100.	5,364.	32,200	24,000.	56,200	5·62	18·7%
3.	35 Lbs/ft	9·5 Lbs/ft	15,950.	9,620.	5,114.	30,680.	21,800.	52,480.	6·10.	17·5%
4.	40 Lbs/ft	10·25 Lbs/ft	15,100.	9,200.	4,860.	29,160.	20,100.	49,260	6·57.	16·4%

Table I shows the results of the weight calculations for these wings. Columns 1 and 2 of this table need no explanation. Column 3 shows the weight in lb. per square ft., which has been allowed as the relieving load on the wings due to the weight of the wings themselves plus engine and fuel weight. Actually the relieving load taken is much less than that which actually occurs, but as the calculations assume that the relieving load is spread uniformly over the wing, the figures given in this table are good enough for the case under consideration. It will be noticed that a greater relieving load in lb. per sq. ft. has been taken as the wing loading increases. This is due to the fact that the relieving load is the sum of the weight of the wings, plus the other load which is in the wings. This other load is practically independent of wing area and is nearly a constant amount. In column 4 will be found the calculated weight of the top and bottom booms of the spar, which requires no further explanation. Column 5 gives the calculated weight of the shear bracing, plus the drag bracing in the fore and aft direction. For the purpose of this table it has been assumed that the drag bracing is the same weight as the vertical shear bracing. In column 6 is an item which has been added to the calculations to allow for joints and for the fact that in some cases it is not practicable to design the spar right down to the calculated sizes. This, in all cases, has been taken as 20 per cent. of the sum of the boom weights plus the shear weights. Column 7 gives the estimated total spar weight, being the summation of the previous columns. Column 8 is an estimation of the additional weight of the wings other than spar weight. This, as will be noticed, is a very large item and is the item most open to question. The assumption made to obtain these weights is that the extra to spar weight in the case of Wing (1) is 2.25lb. per sq. ft., Wing (2) 2.4lb. per sq. ft., Wing (3) 2.55lb. per sq. ft., and Wing (4) 2.7lb. per sq. ft.

Column 9 is the estimated total weight of the wings. Column 10 is the estimated weight of the wings in lb. per sq. ft. Column 11 gives the weight of the various wings as a percentage of the total machine weight. The weight of a cantilever wing for a small flying-boat of, say, 40,000lb., all-up weight would be

in the neighbourhood of 13-14 per cent. of the total all-up weight for a wing loading of 25lb. per. sq. ft. (some modern American boats are better than this)—so it will be seen that it is essential at the present time for the large flying-boat to have a much heavier wing loading, probably approximating to 40lb. per sq. ft. It would appear, therefore, that the wing weight as a percentage of the total weight, is 2 or 3 per cent. greater than on the smaller boat.

Fig. 20 shows the calculated variation of wing weight with wing loading. It is interesting, however, to note that a material 20 per cent. better than the material used in these calculations would result in the wings of the larger boat at 40lb. per sq. ft. being the same percentage of the total weight as with the smaller boat. This high wing loading naturally results in fast landing and take-

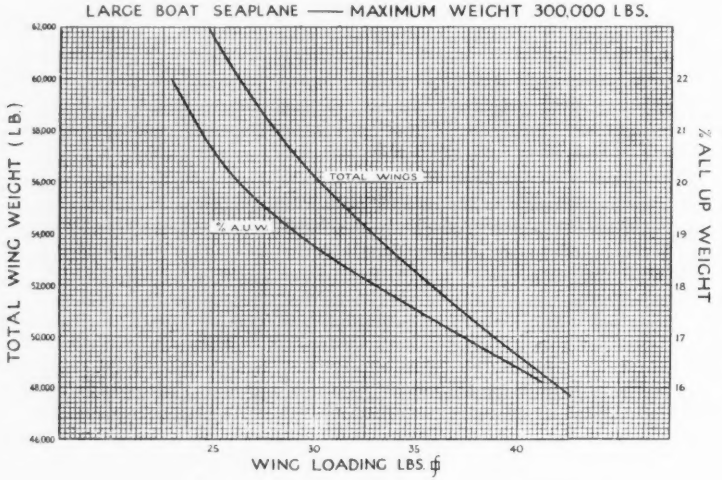

FIG. 20.

Variation of Wing Weight with Wing Loading.

off speeds, and it becomes essential to fit flaps or a similar device in order to reduce these speeds to the absolute minimum. Variable pitch airscrews are also necessary, not only to improve the efficiency of the screws themselves due to the possibility of reducing the pitch angle, but also to take advantage of the extra power which is permitted for take-off purposes.

Fig. 21 illustrates a typical power curve of a modern aero engine and shows clearly the way in which such engines are boosted for performance at altitudes and particularly the additional power available at take-off, without which, the take-off would hardly be possible.

Returning to the weight analysis, it will be seen that the sum of the wing hull weights for the flying-boat under consideration amounts to 29 per cent. of the total weight. The remainder of the structure which includes the tail unit, lateral stabilisers, controls, internal hull structure, etc., probably amounts to about 13 per cent. of the total weight bringing the total structure weight up to 40 per cent. If the reasonable assumption can be made that the weight of the power unit installation would be approximately the same percentage of the all-up weight as for existing flying-boats, then this weight would represent about 17·3 per cent. of the total. For the design of boat we are considering this would result in the following weights:—

Complete structure ...	...	120,000 lb.
Power unit	...	52,000 ,,
Equipment, say, ...	...	10,000 ,,
		182,000 lb.

leaving for fuel, paying load and crew an amount of 118,000lb. For a boat of this weight it would probably be necessary to instal engines developing a total horse-power of about 24,000 b.h.p. For continuous cruising about 16,000 b.h.p. could be employed, which would give a cruising speed of about 165 knots. With the present-day cruising consumption of 0.5 pints per b.h.p. hour the amount of fuel consumed per hour would be 1,000 gallons or roughly 8,000lb. weight per

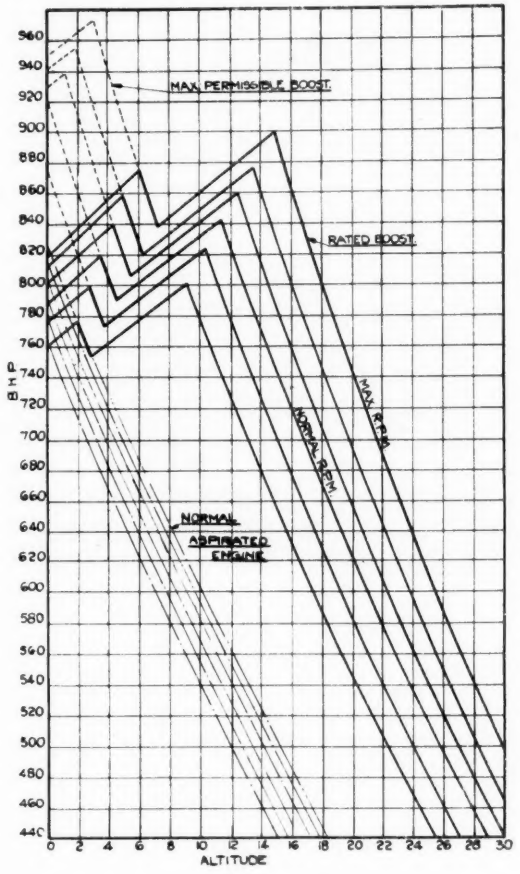

FIG. 21.

Power Curve of Modern Aero Engine.

hour. Assuming the paying load to be in the neighbourhood of 50,00lb., then the range of the boat under these conditions would be about 1,600 statute miles.

This particular example of what might be expected from future development is, of course, only my own personal views and is based on our present rate of progress. Of course there is the possibility that with the advent of new methods of construction, improved materials and better aerodynamic knowledge we may improve on this, at any rate, sufficient to make regular crossings of the North Atlantic with a reasonable pay load. As far as I can foresee it will be at least a matter of ten years hence before we see regular Plymouth-New York crossings in a large flying-boat carrying passengers. This may seem unduly pessimistic taking into account the number of times the Atlantic has been crossed, but it must be borne in mind that all these flights have been carried out with machines loaded far beyond their normal Certificate of Airworthiness weight and it is a far different proposition to run a regular service carrying passengers with a standard of comfort exceeding that now obtained on the London-Paris route.

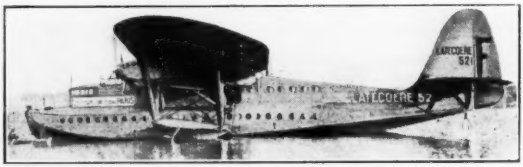

FIG. 22.

Latecoere Commercial Flying Boat—1934.

FIG. 23.

Martin Commercial Flying-boat—1934.

However, the science of aeronautics is still in its infancy and I think it only reasonable to assume that the development of the large aeroplane and particularly the flying-boat will attain a stage of perfection which has now been reached by the mercantile marine. If it does succeed in this then I think we have achieved a goal that has been worth while.

My acknowledgments are due to *Flight*, *Aeroplane*, and the Royal Aeronautical Society for illustrations supplied, and also to my colleagues, Messrs. C. P. Lipscomb and W. Browning, for their help in the preparation of the paper.

APPENDIX.

AN INVESTIGATION INTO SPAR WEIGHTS FOR CANTILEVER WINGS.

The following work assumes that the loading is rectangular and that the spar material is working at its maximum permissible stress over the entire span. The centre of pressure is taken to lie on the spar axis, but to allow for some torsion effect a slightly higher load factor may be used. Relieving load due to

the wing weight is considered and, similar to the lift loading, is assumed rectangular in distribution. Other concentrated loads, namely, engines, wing-tip floats, petrol, etc., have not been taken into account, but this is more or less justified in that it is impossible to design the spar on optimum stress—especially at the wing tips.

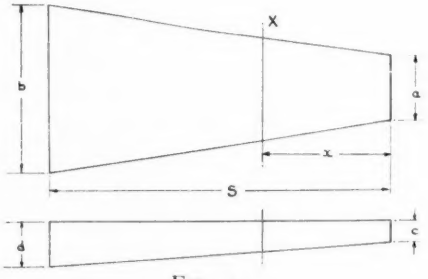

FIG. 24.

Nomenclature :—

Let wing tip to wing root	$=S$ ft.
Tip chord	$=a$ ft.
Root chord	$=b$ ft.
Distance between N.A. of spar at tip	$=c$ ft.
Distance between N.A. of spar at root	$=d$ ft.
All-up weight	$=W$ lb.
Wing weight	$=W_w$ lb. (total).
Assumed load factor	$=F$.
Area (lifting)	$=A=2\left(\frac{a+b}{2}\right)S$ sq. ft. (total).
Factored shear loading	$=w$ lb./sq. ft.
Density of spar material (1 sq. in. section 1ft. long)	$=\Delta$ lb.
Maximum spar stress	$=P$ lb./sq. in.

Then $w=\dfrac{(W-W_w)}{A}\,F=\dfrac{(W-W_w)}{S\,(a+b)}\,F.$

With wing tip as origin, chord at $X=a+(b-a)\,\dfrac{x}{S}$

With wing tip as origin, depth at $X=c+(d-c)\,\dfrac{x}{S}$

Boom Weight.

Loading per unit run of spar at $X=w\left\{a+(b-a)\,\dfrac{x}{S}\right\}$

Shear at $X=w\left\{ax+(b-a)\,\dfrac{x^2}{2S}\right\}$

Bm at $X=w\left\{\dfrac{ax^2}{2}+(b-a)\,\dfrac{x^3}{6S}\right\}$

End load in booms at $X=\dfrac{w\left\{\dfrac{ax^2}{2}+(b-a)\,\dfrac{x^3}{6S}\right\}}{c+(d-c)\,\dfrac{x}{S}}$

$$=\frac{w}{6}\left\{\frac{(b-a)\,x^3+3\,Sax^2}{(d-c)\,x+Sc}\right\}$$

$$\text{Weight of booms per unit run at } X = \frac{\Delta w}{6P}\left\{\frac{(b-a)x^3 + 3Sax^2}{(d-c)x + Sc}\right\}$$

$$\therefore \text{ Total weight of 1 pair of upper or lower booms/side of m/c.} = \frac{\Delta w}{6P}\int_0^s \left\{\frac{(b-a)x^3 + 3Sax^2}{(d-c)x + Sc}\right\} dx$$

$$= \frac{\Delta w}{6P}\int_0^s \left[x^2\left(\frac{b-a}{d-c}\right) + x\left\{\frac{3Sa - Sc\left(\frac{b-a}{d-c}\right)}{d-c}\right\} - Sc\left\{\frac{3Sa - Sc\left(\frac{b-a}{d-c}\right)}{(d-c)^2}\right\} + \frac{S^2c^2\left\{3Sa - Sc\left(\frac{b-a}{d-c}\right)\right\}}{(d-c)^2\{(d-c)x + Sc\}}\right] dx$$

$$= \frac{\Delta w}{6P}\int_0^s \left[x^2\left(\frac{b-a}{d-c}\right) + x\left\{\frac{3 \cdot Sa - Sc\left(\frac{b-a}{d-c}\right)}{(d-c)}\right\} - Sc\left\{\frac{3 \cdot Sa - Sc\left(\frac{b-a}{d-c}\right)}{(d-c)^2}\right\}\right] dx + \frac{S^2c^2\left\{3 \cdot Sa - Sc\left(\frac{b-a}{d-c}\right)\right\}}{(d-c)^2}\int_0^s \frac{dx}{(d-c)x + Sc}$$

$$= \frac{\Delta w}{6P}\left[\frac{x^3}{3}\left(\frac{b-a}{d-c}\right) + x^2\left\{\frac{3Sa - Sc\left(\frac{b-a}{d-c}\right)}{2(d-c)}\right\} - Sc\left\{\frac{3Sa - Sc\left(\frac{b-a}{d-c}\right)}{(d-c)^2}\right\}x + \frac{S^2c^2\left\{3 \cdot Sa - Sc\left(\frac{b-a}{d-c}\right)\right\}}{(d-c)^2}\left\{\frac{1}{(d-c)}\log_e[(d-c)x + Sc] + K\right\}\right]_0^s$$

This is zero when $x = 0$ $\therefore K = -\frac{1}{(d-c)}\log_e Sc$.

Substituting we have boom weight

$$= \frac{\Delta w}{6P}\left[\frac{x^3}{3}\left(\frac{b-a}{d-c}\right) + x^2S\left\{\frac{3a - c\left(\frac{b-a}{d-c}\right)}{2(d-c)}\right\} - xS^2c\left\{\frac{3a - c\left(\frac{b-a}{d-c}\right)}{(d-c)^2}\right\} + \frac{S^3c^2\left\{3a - c\left(\frac{b-a}{d-c}\right)\right\}}{(d-c)^3}\{\log_e[(d-c)x + Sc] - \log_e Sc\}\right]_0^s$$

$$= \frac{\Delta w}{6P}\left[\frac{S^3}{3}\left(\frac{b-a}{d-c}\right) + \frac{S^3}{2}\left\{\frac{3a(d-c) - c(b-a)}{(d-c)^2}\right\} - S^3c\left\{\frac{3a(d-c) - c(b-a)}{(d-c)^3}\right\} + \frac{S^3c^2\{3a(d-c) - c(b-a)\}}{(d-c)^4}\log_e\frac{d}{c}\right]$$

$$= \frac{\Delta wS^3}{6P}\left[\frac{b-a}{3(d-c)} + \frac{3a(d-c) - c(b-a)}{2(d-c)^2} - \frac{c\{3a(d-c) - c(b-a)\}}{(d-c)^3} + \frac{c^2\{3a(d-c) - c(b-a)\}}{(d-c)^4}\log_e\frac{d}{c}\right]$$

This expression gives the *sum of the weights* of a pair of upper booms *or* a pair of lower booms on one side of the machine only—the appropriate stress being used in each case.

Shear Bracing.

The following work assumes that the diagonal members are at an angle of 45 degrees.

Nomenclature.—As before, except that tension stress for diagonals $= P_1$ and compression stress for verticals is P_2.

Δ is again the density of the material.

Verticals.—Shear at $X = w\left\{ax + (b-a)\frac{x^2}{2S}\right\}$

and total length of verticals = semi-lifting span S.

$$\therefore \text{ weight of verticals} = \frac{w\Delta}{P_2}\int_0^S \left\{ax + (b-a)\frac{x^2}{2S}\right\} dx$$

$$= \frac{w\Delta}{P_2}\left[\frac{ax^2}{2} + \frac{(b-a)x^3}{6S}\right]_0^S$$

Diagonals.—Load in diagonal at $X = \sqrt{2}w\left\{ax + (b-a)\frac{x^2}{2S}\right\}$

and total length of diagonals = semi-lifting span $S \times \sqrt{2} = \sqrt{2} \cdot S$.

$$\therefore \text{ weight of diagonals} = \frac{2w\Delta}{P_1}\int_0^S \left\{ax + (b-a)\frac{x^2}{2S}\right\} dx$$

$$= \frac{2w\Delta}{P_1}\left[\frac{ax^2}{2} + \frac{(b-a)x^3}{6S}\right]_0^S$$

Weight of diagonals and verticals on one side of machine

$$= w\Delta\left[\frac{ax^2}{2} + \frac{(b-a)x^3}{6S}\right]_0^S\left(\frac{1}{P_2} + \frac{2}{P_1}\right)$$

$$= \frac{w\Delta S^2}{6}(2a+b)\left(\frac{2}{P_1} + \frac{1}{P_2}\right)$$

Summary.

Booms.

Weight of one pair of top *or* bottom booms on one side of machine only :—

$$= \frac{\Delta w S^3}{6P}\left[\frac{b-a}{3(d-c)} + \frac{3a(d-c) - c(b-a)}{2(d-c)^2} - \frac{c\{3a(d-c) - c(b-a)\}}{(d-c)^3} + \frac{c^2\{3a(d-c) - c(b-a)\}}{(d-c)^4}\log_e\frac{d}{c}\right]$$

where P is the appropriate spar stress.

Shear Bracing.

Weight of shear bracing on *one* side of machine only :—

$$= \frac{w\Delta S^2}{6}(2a+b)\left(\frac{2}{P_1} + \frac{1}{P_2}\right)$$

where P_1 is the diagonal stress and P_2 the vertical stress.

Discussion

Mr. H. Sammons: Are any Diesel engines in commercial use in aircraft in this country?

The Junker Company in Germany had one of their 550 b.h.p. Diesel aero engines on exhibition at the Berlin Show in February. The advertised weight of this engine was 2lb. per b.h.p. It also gave an output of about 25 b.h.p. per litre, which was very near the figure quoted by the Author as being the present-day output of a petrol engine.

I was informed in Germany that these engines were in regular commercial service and were giving extremely satisfactory results. In my opinion the best hope for a satisfactory Diesel engine for aircraft work lies in the development of the two-stroke cycle engine. It has proved possible to obtain commercial results with a two-stroke cycle engine giving the same brake mean effective pressure as the four-stroke and, assuming the same engine speed, this engine would give double the horse-power per litre capacity of the four-stroke Diesel.

Would the Author give his opinion on these points?

The CHAIRMAN (Mr. H. G. Williams, O.B.E., Fellow): As the Author is no doubt aware, the engineering and shipbuilding industries in which this district is chiefly engaged are of the " heavy " description and, as far as I know, the aeroplane industry which flourished here during the war has died an untimely death. Probably, therefore, there are no members here to-night who have been recently engaged in the design or construction of aircraft, and that is, no doubt, the reason why the very instructive and interesting paper which we have heard to-night, has not met with the volume of criticism and appreciation to which papers read before this Institution are usually subjected. No doubt other members feel as I do that no one without a large practical experience in the design and construction of such specialised structures and machines as flying boats has the right either to agree with or disagree with the conclusions as to the possible development of such craft, which have been arrived at by an expert of the calibre of the Author.

We are, of course, familiar in their application to ordinary ships and boats, with the kind of considerations which enter into the Author's reasoned forecast of the development of flying-boats, such as the hydrodynamic and strength qualities of the structure, and the power and weight properties of the machinery, to which Mr. Sammons has referred. The resistance speed curve of a flying-boat hull shown on the screen, resembles that of an ordinary hull if the latter could only be driven fast enough to pass the critical point where resistance begins to fall as speed increases. The best part of a century ago it used to be called the " Ramus " effect after the Rev. Mr. Ramus who first predicted that it would be found to occur in flat-bottomed ships. Even 40 years or so ago it was regarded merely as a scientific curiosity as it was not foreseen that any floating structure could be so light and any machinery so powerful in relation to its weight as to make the reduction of resistance due to planing a practical possibility. The occurrence of this type of resistance curve in the flying-boat, though no doubt the position of the critical point on the speed scale is largely due to the lift of the aeroplane wings, bears witness to the progress in design of structure and machinery which has taken place in recent years.

Another diagram, Fig. 12, shows that the maximum speed of flying-boats has increased from about 90 miles per hour in the year 1917 to about 190 miles per hour in 1934, approximately according to a straight line law. The straight line produced gives a maximum speed of about 340 miles per hour for the year 1963, and I think the Author almost apologised for limiting himself to so " pessimistic " a forecast. I do not propose to offer an opinion on the pessimism or optimism of this forecast, but I think history shows that engineering progress seldom goes on for long according to a straight line law on a base of time. Fundamental inventions and discoveries cause a jump in progress followed by a declining rate until the next invention produces another discontinuity in the curve.

However that may be, the Author has shown us very clearly the reasoning on which his forecast of progress is based. The production of the paper must have given him a great deal of work, and I can assure him that the absence of comment on our part is not due to any lack of interest, but simply to our feeling that in this particular subject he is beyond our criticism. I beg to move that a

hearty vote of thanks be accorded to the Author for his interesting and valuable paper.

Vote of Thanks

The vote of thanks moved by the Chairman (Mr. H. G. Williams, O.B.E., Fellow), was carried with acclamation.

Correspondence

Mr. G. S. Baker, O.B.E., Member: The time had obviously come when attention should again be turned in England to the design of large flying-boats, and it is good to have this subject introduced before our Institution by one who holds a responsible position in the production and design of such vessels. I suppose, too, that it is inevitable that this first approach by Mr. Gouge should be of a fairly general character. The "Atalanta" and "Do. X" experiments have taught us a good deal about the design of hulls for large flying vessels, but not so much about the engines. Possibly it is because of this that the Author has gone into the hull question a little closely, and left the engine side in a somewhat sketchy fashion. For instance, he speaks of such a vessel having "six engines," each a group of small ones; these latter to be mounted as one unit geared to a common propeller axis—presumably driving tandem propellers. The weights of the engines alone here would be about 30,000lb., leaving 22,000lb. in the Author's estimate for propellers, shafting, gearing and seatings and structural supports. Has the Author any basis for this allowance?

Some difficulties can be seen with a rigid unit of this kind on a flexible structure, and I notice that in the Appendix the stresses in the spars due to these rather serious items are not taken into account. If the drive of the four-unit engines is through a single tractor propeller, this becomes very large, and hence the spread of the six engines also becomes large, and the spar stresses again increase.

One other matter connected with these stresses is the treatment of landing stresses. These can be considered in two different ways, the general and local. The bending and shear stresses in the bottom, and in the sides between wing and bottom are calculable, and one assumes that the thickness of skin varying as $(\text{weight})^{\frac{2}{3}}$ is based on such a calculation. But the local stresses are on a different footing. Vertical decelerations of the hull bottom vary as the speed. With present landing speeds these may reach $2g$, and would be higher with the higher landing speeds necessary with heavier wing loading, and it is difficult to see how this speed factor is eliminated by the Author. It seems to me a very essential matter and like the elasticity of the structure, one which cannot be left out. This brings me to a question I should like to ask: Does the Author consider that future hulls will be of the braced rigid type with little or no elasticity, or of the light river steamer type, allowing of some bending and deformation?

Mr. E. C. Gordon England: I should have liked to hear something from Mr. Gouge on the subject of take-off and landing speeds. As I understand it, in this country we have grown up with the idea that low take-off and landing speeds are essentials in flying-boat design. It seems to me that if these factors are accepted as of prime importance, they must largely affect the tendency of future design, almost becoming a limitation to progress.

The Author refers to the three well known ways of obtaining lateral stability for the hull, and it would have been interesting if he could have developed more fully the pros and cons of these three systems, particularly in relation to take-off and landing speeds. Is it not possible that we have in this country retained the small stabilising floats near the wing tips because of our low take-off and landing speeds? These might be ruled out as impracticable were we to

agree that our take-off and landing speeds should be raised substantially. I should have thought that it could have been proved in the wind tunnel that a hull with well-designed sponsons would have the least parasitic drag and interference of the three types. It would appear to have the great advantage of removing stresses of what seem a most undesirable character from being transmitted to the wing structures.

As the adoption of large flying-boats for commercial purposes will be governed by the possibility of operating them at economic figures, it seems regrettable that Mr. Gouge has not been able to provide us with some additional graphs showing the operating costs per hour of up-to-date flying-boats. If he could supply these, it would add substantially to the value of an already wholly admirable paper.

Author's Reply

Regarding the comment of Mr. Williams on the probable future speed of flying-boats, I admit that these may not progress exactly as a straight line law if operating altitudes are kept to the present-day limits. However, I believe that operating altitudes will steadily increase until finally, stratosphere flying may become a possibility. When this is achieved, I believe it possible for aircraft speeds to increase even greater than the straight line law would predict. This is pure conjecture and only time will prove the validity of this assumption.

In reply to Mr. Baker, to whom all flying-boat constructors are much indebted for the very valuable work he did in the early days of flying-boat development, his assumption regarding the probable weight of the engines is correct. An approximate estimate was made from present-day experience of the weight of the remaining items of the power unit and I am of the opinion that this should not exceed 22,000-25,000lb. The weight of the gearing and transmission is undoubtedly an unknown factor, but off-setting this is the possibility of two engines per unit being employed which would tend to keep down the weight of these components. Actually, present-day engines were taken as the basis for the estimate, but engines of 2,000 h.p., would in all probability be available by the time such an aircraft was built. No actual structural items were included under this heading.

I should not anticipate any difficulty due to mounting the engines in the wings. Actually the wing would be stiffer than the wings of present-day machines, owing to the higher wing loading. The net effect of the engine weight is rather as a relieving load and, therefore, the spar stresses would tend to decrease with an increasing spread of the engines.

Regarding the local strength of the planing bottom, it is quite true that with much higher landing speeds the effect of the vertical decelerations would need to be seriously considered. It is not anticipated, however, that the landing speeds will materially increase, as even with information available at the present time it is possible, by the use of special flaps, etc., almost to double the lift coefficient of the basic wing and with the margin we already have in hand against exceptional bad landings, the increase in weight due to local loads would not be of a high order.

Dealing with Mr. Baker's last question, I am of the opinion that future hulls will be of the braced rigid type with a concave under-water surface, this being the best shape for taking the planing bottom loads.

In reply to Mr. England, I think it is generally accepted that the take-off and landing speeds of flying-boats can be rather higher than those of the corresponding landplane, and in my opinion these speeds can safely be in the neighbourhood of 65-70 knots. Of course, in restricted harbours it may be desirable to employ lower speeds, but I do not think this need be considered with the type of boat under discussion. As mentioned in the reply to Mr. Baker, devices can be employed on boats with high wing loading to bring down the take-off and landing speeds to the figures mentioned above.

Mr. England has raised rather a controversial point when he mentions the case for stabilising sponsons as against the wing-tip float. From my experience in the past I should have said that the wing-tip float is preferable to any method of stabilisation on the score of weight, aerodynamic drag and hydrodynamic resistance. This view is not altogether shared by many authorities, including the R.A.E. research staff at Farnborough; but, nevertheless, I see no reason why wing-tip floats should not have less disadvantages than other methods. The increase in take-off speeds would be rather against the sponson type, as they are actually in the water a longer period during the take-off than are wing-tip floats. The wings certainly do get stressed by the wing-tip float loads, but this is taken account of in the design.

Regarding operating costs, I should very much have liked to give Mr. England some figures on this point, but, unfortunately, being only a constructor, I could not speak with sufficient authority. Many factors enter into what might be called the economic cost of operation, the chief of which being the revenue-earning capacity. This depends on the length of the stages, as at the limiting range no revenue at all would be earned. The operational costs of such a boat with a range sufficient for crossing the Atlantic would, in the light of our present knowledge, be very high and that is one reason why I expect regular crossings commercially will not mature for at least another ten years.

Replying to Mr. Sammons' inquiry, there are no compression-ignition engines installed at present in commercial aircraft in this country. About thirty-five designs of such engines have been produced in various countries, a few of which might be considered as conversion types and of these about half are of the two-stroke type. Among the four-stroke engines, work has been concentrated about equally between the liquid- and air-cooled types with perhaps more success with the air-cooled. Of the two-stroke type, all except one are liquid cooled, the most successful engine of this type being the Junker engine. Taking even the latest model of this engine which has a rated power of 720 b.h.p., the weight per b.h.p. of the dry engine without considering the cooling plant is 2.25lb.

The chief difficulty of the two-stroke engine is to obtain satisfactory scavenging and, also, a low fuel consumption; nevertheless, I agree with Mr. Sammons that the most promising line of development is with the two-stroke type, but we must not expect any rapid or striking developments; progress will be slow but probably sure. In the meantime, as stated in my paper, the petrol engine will probably more than hold its own for some years, especially in flying-boat work.

TRANSVERSELY LOADED FRAMEWORK MEMBERS

BY

N. J. HOFF

§1. Introduction

The standard method of strength calculation of a framework is based on the assumption that members are freely pinned together and external forces are applied only at nodes. Actually aircraft fuselage members are stiffly joined and transverse forces are often acting on them at considerable distances from nodes, *e.g.*, weights of crew, instruments and oil, reactions of controls, stabiliser adjusting gear, etc.

The safest method of computing stress in such members is to assume both ends pin-jointed. As they actually are stiffly connected to adjacent members, they are not allowed to twist freely, *i.e.*, the truss exerts moments on the loaded member. The effect of these end moments consists in diminishing deflection and field moments. The decrease of maximum bending moment may attain nearly 50 per cent.

Since framework members are designed to withstand axial forces only, viz., tension or compression, they are comparatively weak against bending and have to be strengthened appreciably if transverse forces are present. For saving unnecessary weight it is therefore of great importance to calculate the magnitude of end moments.

These being dependent upon the point of application of the transverse force, the stiffness of encastrement of the ends and finally upon the variation along the member of the product of moment of inertia of the cross section by Young's modulus, the calculation is somewhat complicated. By the introduction of the relative stiffness factor (R.S.F.) correlating the stiffness of the bended member to that of the encastrement of the ends, an analytical treatment of the problem was made possible. To make results easily accessible for the daily use in the drawing office, Fig. 2 shows a diagram of the end moments as plotted against the points of application of the transverse force for different values of the relative stiffness factor.

The calculation may be of practical value only in case the elastic properties of encastrement have numerically been determined. This may be done either experimentally or theoretically. The latter method has been used in the case of a framework by computing the stiffness of a joint against torque.

To check the validity of assumptions made and results obtained some experiments have been carried out on two frameworks made for that purpose. These experiments are described under §§4 and 7 and results discussed under §§5 and 9.

§2. Determination of End Moments

Fig. 1 shows a girder on two supports, on which a transverse force and two end moments are acting. In the following we shall denote a force positive, which is acting downward and a moment positive, which produces tension in the lower fibres. The force W causes a positive area of moments and since end moments are assumed here negative, the resulting moment M_x is the ordinate of the shaded area.*

* This method of graphical representation of moments is dealt with *in extenso* in Mr. Howard's book on "The Stresses in Aeroplane Structures."

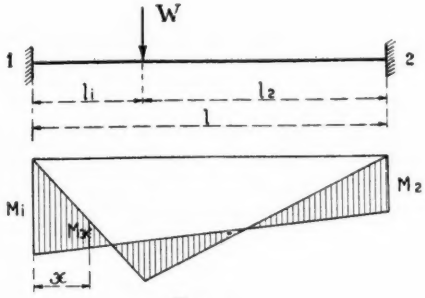

FIG. 1.

Between support 1 and the external force, *i.e.*, when

$$0 < x < l_1$$

this moment may be expressed

$$M_x = M_1 + R_1 x$$

where

$$R_1 = W\,(l_2/l) + (M_2 - M_1)/l$$

and thus

$$M_x = M_1 + W\,(l_2/l)\,x + (M_2 - M_1)\,x/l \qquad . \quad . \quad . \quad (1)$$

In like manner we get between force W and support 2, *i.e.*, when

$$l_1 < x < l$$

$$M_x = M_2 + W\,(l-x)\,(l_1/l) - (M_2 - M_1)\,(l-x)/l \qquad . \quad . \quad (1a)$$

In order to get the slope of the neutral axis at the support we make use of the First Theorem of Castigliano.* According to this the partial differential coefficient of the total strain energy stored in an elastic body or a framed structure expressed in terms of the external load system, consisting of forces and moments, with respect to one of the moments, is the angular displacement of the point of application of that moment in its own direction.

The strain energy stored in the girder due to bending is given by

$$U = \int M_x^2 dx / 2EI$$

and to get the slope of the bending line at support 1, *i.e.*, at the point of application of the end moment M_1, we have to differentiate above expression with respect to M_1; thus we get for the twist at support 1 :—

$$\theta_1 = \partial U / \partial M_1 \qquad . \quad . \quad . \quad . \quad . \quad (2)$$

Assuming the product EI a constant we get

$$\theta_1 = (1/EI) \int M_x\,(\partial M_x / \partial M_1)\,dx$$

$$= (1/EI) \int_0^{l_1} \{\, M_1 + W\,(l_2/l)\,x + (M_2 - M_1)\,x/l \,\}\,(1 - x/l)\,dx$$

$$+ (1/EI) \int_{l_1}^{l} [\, M_2 + Wl_1\,(l-x)/l - (M_2 - M_1)\,(l-x)/l \,]\,(1 - x/l)\,dx$$

$$\theta_1 = (l/6EI)\,[\,2M_1 + M_2 + l_1 l_2\,(l_1 + 2l_2)\,W/l^2\,] \qquad . \quad . \quad (3)$$

* See "Strain Energy Methods," by A. J. S. Pippard.

For reasons of symmetry we may write

$$\theta_2 = (l/6EI)\,[M_1 + 2M_2 + l_1 l_2\,(2l_1 + l_2)\,W/l^2] \quad . \quad . \quad (3a)$$

In case of an elastically encastred transversely loaded girder W is the known external force and M_1 and M_2 are the unknowns to be computed. Since θ_1 and θ_2 are also unknown, we have four unknowns in all, but only two equations. The missing two equations may be found, if we make an assumption on the elastic properties of the supports, *i.e.*, in case of a framework on the stiffness of joints supporting the loaded member. We write

$$\theta_1 = \Phi_1 M_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$\theta_2 = \Phi_2 M_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (4a)$$

where M_1 and M_2 are the unknown moments exerted by the bended member on the supports and Φ_1 and Φ_2 are regarded as known quantities characterising the supports. Their value will be computed in §3.

Equating the right hand sides of equations (3), (4), and (3*a*), (4*a*), respectively, and substituting for Φ the expression

$$\Phi = (l/EI)\,\Omega \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where E, I and l are Young's modulus, moment of inertia of the cross section and length of the loaded member respectively. By Ω we want to denote here the relative stiffness factor.

From equations (3), (4) and (5) we get

$$l/6EI\,[2M_1 + M_2 + l_1 l_2\,(l_1 + 2l_2)\,W/l^2] = -\Phi_1 M_1 = -(l/EI)\,\Omega_1 M_1$$

The negative sign has been used on the right hand side since the moment acting on support 1 is the reaction of the end moment acting on member 1-2. Multiplying by $6EI/l$ and transposing Ω_1 we may write

$$(2 + 6\Omega_1)\,M_1 + M_2 + l_1 l_2\,(l_1 + 2l_2)\,W/l^2 = 0 \quad . \quad . \quad . \quad (6)$$

In like manner we get

$$M_1 + (2 + 6\Omega_2)\,M_2 + l_1 l_2\,(2l_1 + l_2)\,W/l^2 = 0 \quad . \quad . \quad . \quad (6a)$$

Solving for M_1 we have

$$M_1 = -(l_1 l_2/l^2)\,[\,\{\,l_2 + (2l_1 + 4l_2)\,\Omega_2\,\}\,/\,\{\,1 + 4\Omega_1 + 4\Omega_2 + 12\Omega_1\Omega_2\,\}\,]\,W \quad (7)$$

In case of equal end constraint at both ends above expression may be simplified:—

$$M_1 = -(l_1 l_2/l^2)\,[\,\{\,l_2 + (2l_1 + 4l_2)\,\Omega\,\}\,/\,\{\,1 + 8\Omega + 12\Omega^2\,\}\,]\,W \quad . \quad (8)$$

In case when both ends are rigidly encastred ($\Omega = 0$) we have

$$M_1 = -(l_1 l_2^2/l^2)\,W$$

and when the member is loaded at mid-beam we get the well-known formula

$$M_1 = Wl/8$$

In Fig. 2 end moments are plotted against points of application of the external force for different values of the R.S.F. as calculated from equation (8). To make the diagram valid for both British and metric systems, non-dimensional coefficients have been used only, viz., the ratio M_1/Wl for the end moment, the ratio l_1/l for the points of application and the R.S.F. which is also a non-dimensional coefficient as stated above. Since M_2 may always be regarded as M_1, supposing the origin of co-ordinates be taken at support 2 instead of support 1 and the x-axis be drawn to the opposite direction, it is superfluous to establish a new diagram for M_2. To determine end moments equations (7) and (8) may also be used, only l_1 is to be measured from the point of application of the force W to support 2 and l_2 to support 1.

Fig. 2 shows clearly the influence of the R.S.F. on end moments as it will be best understood from an example. The girder be loaded at mid-beam,

$l_1/l=l_2/l=l/2$. For $\Omega=0.30$, *i.e.*, an extremely stiff girder as compared with the stiffness of supports, we get

$$M_1=M_2=-0.078\ Wl$$

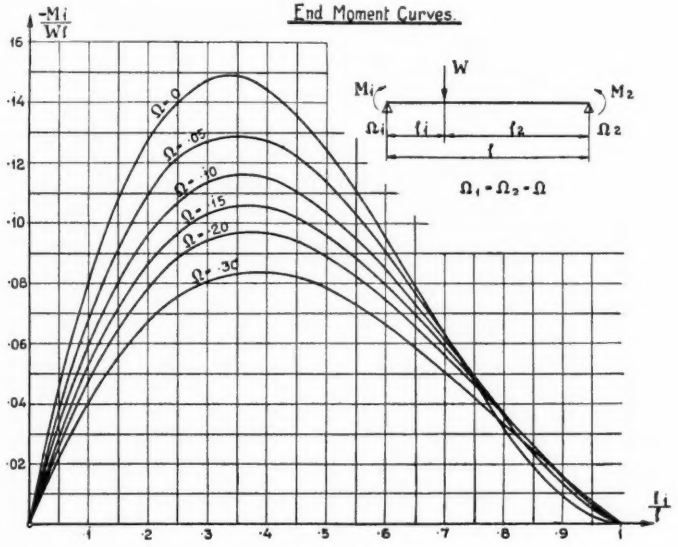

FIG. 2.

Since the maximum moment of the free girder (pin-jointed ends) is

$$M=0.25\ Wl$$

we get a moment diagram as illustrated in Fig. 3. The maximum resulting moment is thus

$$M_{max}=(0.25-0.078)\ Wl=0.172\ Wl$$

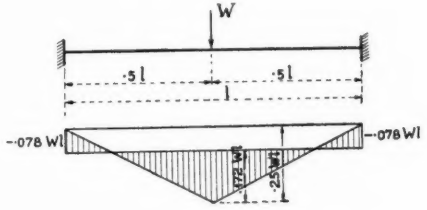

FIG. 3.

In this extreme case maximum moment decreased by 31 per cent. With relatively stiffer supports reduction increases. In the case of total rigidity, $\Omega=0$, we may take from Fig. 2:—

$$M_1=M_2=-0.125\ Wl$$

which means a reduction by 50 per cent.

If the girder be loaded at one-third of the beam, $l_1/l=l/3$, a reduction of 50 per cent. is possible without rigid encastrement. In this case with $\Omega=0.05$ we have

$$M_1=-0.129\,Wl \qquad M_2=-0.073\,Wl$$
$$M=(2/9)\,Wl=0.222\,Wl$$

Maximum moment has been therefore reduced from $0.222\,Wl$ to $0.11\,Wl$ (Fig. 4), *i.e.*, by 50 per cent. This is not, however, the case with the maximum

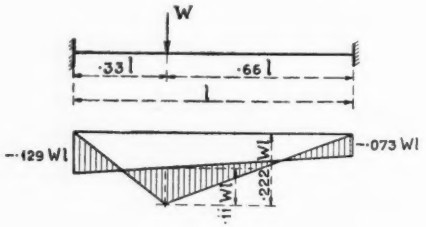

FIG. 4.

stress. The end moment at support 1 will be now greater than the maximum resulting field moment. Since in case of a smaller value of Ω the resulting field moment falls out greater, and the end moment smaller than calculated above, obviously there exists for any point of application of the external force an optimum value for the R.S.F. at which the stress is a minimum.

Since values of the R.S.F. obtained in actual framework are comparable to those used in above calculations, as it will be shown in §3, it is obvious that maximum stress will appreciably be diminished by end moments.

§3. THE RELATIVE STIFFNESS FACTOR

In this paragraph we propose to compute the R.S.F. in the case, when the transversely loaded girder is a framework member. If it is not so, other methods are to be developed or tests have to be carried out in each special case.

The R.S.F. has been defined by equation (5). It may be seen from this definition and from equation (4) that the first step to be made, when calculating the R.S.F., is to determine the twist of a node due to a unit moment applied to it.

If we assume that linear displacements of nodes in a frame due to torque applied to one of them are negligible and members are rigidly connected at nodes, the slope of the bending line of any member at the node where the external moment is acting will be equal to the twist of this node. Consequently the external moment will be distributed between members in such proportion as to cause equal slope of every member.

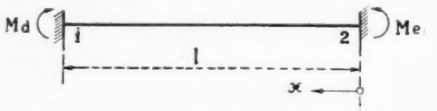

FIG. 5.

This slope may be calculated in the following way. Be M_d the moment which has been the share of member 1-2 after the external moment applied at node 1 has been distributed between members (Fig. 5). It will produce an encastré moment M_e at support 2 since this end of the member is assumed to be

rigidly connected to members meeting at node 2. If we take the origin of co-ordinates at this point, we may write

$$M_x = M_e + (M_d - M_e)\, x/l$$

The strain energy stored in the member will be

$$U = (1/2EI)\int \{ M_e + (M_d - M_e)\, x/l \}^2\, dx$$

We may find the slope of the bending line at support 2, if we make use of the First Theorem of Castigliano as explained in §2 :—

$$\theta_2 = \partial U/\partial M_e = (1/EI)\int_0^l \{ M_e + (M_d - M_e)\, x/l \}\, (1 - x/l)\, dx$$

$$= (l/6EI)\, (M_d + 2M_e) \quad . \quad . \quad . \quad . \quad . \quad (9)$$

We may express the twist θ_2 also by assuming the twist due to a unit moment of support 2 as a known quantity. In this case we have in accordance with equations (4) and (5) :—

$$\theta_2 = -\Phi_2 M_e = -(l/EI)\, \Omega_2 M_e$$

Equating both expressions and solving for M_e we get

$$M_e = -M_d/(2 + 6\Omega_2) \quad . \quad . \quad . \quad . \quad (10)$$

In this expression Ω_2 is, of course, unknown. We may give, however, the limits of its value. If member 1-2 is pin-jointed at support 2, an infinitely small moment applied to the member at support 2 will be able to produce finite distortions. Evaluating the magnitude of Φ from equation (4) we get

$$\Phi_2 = \infty \quad \Omega_2 = \infty \quad M_e = 0$$

In case of rigid encastrement at support 2 only an infinitely large moment could produce finite distortions :—

$$\Phi_2 = 0 \quad \Omega_2 = 0 \quad M_e = -M_d/2 \quad . \quad . \quad . \quad . \quad (10a)$$

The encastré moment is one-half of the external moment in case of rigid encastrement. This shows an agreement with results derived by other methods.

Now we are able to compute the twist at support 1. We could differentiate the expression of the strain energy with respect to M_d, but it is simpler to make use of the symmetry of the system and change suffixes d and e in equation 9. Thus we have

$$\theta_1 = (l/6EI)\, (2M_d + M_e)$$

and substituting for M_e the expression given by equation (10) we get

$$\theta_1 = (M_d l/6EI)\, \{ 2 - 1/(2 + 6\Omega_2) \} \quad . \quad . \quad . \quad (11)$$

With the limits for Ω_2 as stated above we have, if member is pin-jointed at support 2 :—

$$\theta_1 = (M_d l/6EI)\, (2 - 0) = M_d l/3EI \quad . \quad . \quad . \quad (11a)$$

if member is rigidly encastred at support 2 :—

$$\theta_1 = (M_d l/6EI)\, (2 - 0.5) = M_d l/4EI \quad . \quad . \quad . \quad (11b)$$

In an actual frame the ends of members are elastically encastred, *i.e.*, they are between both extreme cases discussed above. Generally we may write

$$\theta = Ml/fEI \quad . \quad . \quad . \quad . \quad . \quad (12)$$

We know that in this expression the stiffness factor f may attain values between 3 and 4, but we cannot directly estimate its magnitude with any accuracy between these two limits. A preliminary estimation, however, of the ratio of the stiffness of node 1 to the stiffness of node 2 (or, being the same, the ratio of the twist factors of nodes 2 to 1) is possible. In the following calculation we shall denote

$$m = \Phi_2/\Phi_1 = \Omega_2/\Omega_1 \quad . \quad . \quad . \quad . \quad . \quad (13)$$

It may be remembered that R.S.F. is a measure of the relative stiffness of the member to the stiffness of the node, and thus the stiffer the node the smaller Ω. Φ being the twist due to a unit moment, it is a measure for the deformability, not for the stiffness of the node.

We assume that

(1) The number of members joined at node 1 is n;
(2) The members are of equal length, cross section and material;
(3) The external moment M is applied at node 1.

In this case moment M will be equally distributed between members meeting at node 1 and consequently each member will be loaded with M/n. With respect to equation (11) we get for the slope at support 1

$$\theta_1 = (Ml/6nEI)\ \{\ 2 - 1/(2+6\Omega_2)\ \}$$

On the other hand, we may compute the twist of node 1 due to moment M. In accordance with equations (4) and (5) we have

$$\theta_1 = \Phi_1 M = l\Omega_1 M/EI$$

Equating both expressions and putting $\Omega_2 = m\Omega_1$ and finally solving for Ω_1, we get

$$\Omega_1 = (1/6mn)\ [m - n \pm (m^2 + mn + n^2)^{\frac{1}{2}}] \quad . \quad . \quad . \quad (14)$$

In virtue of equations (4), (5) and equations (14), (12) we may write

$$\theta_1 = l\Omega_1 M/EI = Ml/nfEI$$

Solving for f we get

$$f = 1/n\Omega_1 \quad . \quad . \quad . \quad . \quad . \quad (15)$$

Fig. 6 shows how stiffness factor f varies as the ratio $m = \Omega_2/\Omega_1$ changes. Values have been calculated with the aid of equations (14) and (15), putting

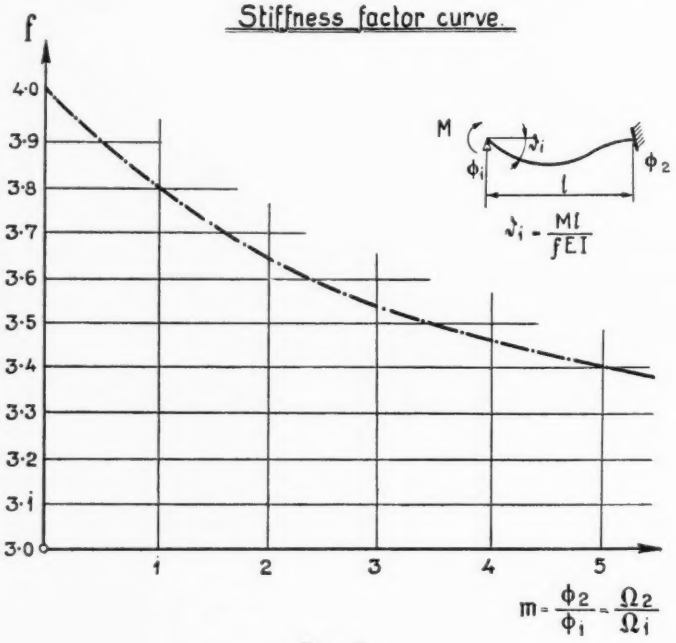

FIG. 6.

$n=4$. With other customary values the difference is not substantial. It may be seen from Fig. 6 that for equal stiffness of both ends the value of f is equal 3.8. If the node at which the external moment acts is less stiff than the other end of the member, *i.e.*, $m<1$, the factor f nearly attains the value 4; in the opposite case, viz., $m>1$, it approaches towards 3, but very gradually.

In possession of the value of the stiffness factor f we may proceed now with the determination of the twist of node 1, due to a unit moment applied to it. To this end we estimate the ratios $\Phi_2/\Phi_1=\Omega_2/\Omega_1=m$ for each member joined at the node under consideration and take the respective values of f from Fig. 6. With respect to equation (12) we have

$$\theta_1=M_I l_I/f_I E_I I_I,\ \theta_{II}=M_{II}\, l_{II}/f_{II}\, E_{II}\, I_{II},\ \ldots\ \theta_n=M_n l_n/f_n E_n I_n$$

where M_I, $M_{II}\ldots M_n$ are the moments acting at node 1 on members I, $II\ldots n$, respectively, and θ_I, $\theta_{II}\ldots\theta_n$, the slopes of the centre lines of the same members at node 1.

In accordance with the statement at the beginning of this paragraph we may write

$$\theta_I=\theta_{II}=\ \ldots\ =\theta_n=\theta$$

The sum of the moments acting on members must be equal to the external moment

$$M_I+M_{II}\ldots M_n=M$$

Young's modulus being the same mostly for every member we get

$$\theta=M/E\Sigma\,(fI/l)=\Phi M$$

and thus

$$\Phi=1/E\Sigma\,(fI/l) \qquad (16)$$

Under the summation in the denominator all members are contained which meet at the node under consideration. In the case, however, when the R.S.F. of a support of a transversely loaded member has to be computed the loaded member must not be taken into account since it transmits the external moment to the node and consequently cannot give any reaction moment.

Having got the magnitude of the twist of the node due to a unit moment we may easily calculate the R.S.F. According to equation (5) we have to multiply the twist by Young's modulus and the moment of inertia of the cross section and to divide it by the length of the transversely loaded member.

In order to check results thus obtained, some experiments have been carried out. These will be described in §4 and results obtained discussed in §5. The tests gave a stiffer node than our calculation. In order to find the cause of this discrepancy a member has been cut out of the experimental girder, and loaded without end moments when supported at both ends. Deflections have been found in full agreement with the general bending theory. Consequently the explanation may be given in the following. In our calculations we measured the lengths of members between intersection points of centre lines of tubes. This full length has been assumed to have a constant moment of inertia. Actually members have been welded together and thus their ends formed part of a rather bulky joint.

In order to establish a theory of better accordance with fact, we assume both ends rigid between intersection point of centre lines and the end of weld. We could proceed now in the same way as before to get the encastré moments and the distortions, only we have one parameter more, viz., the length of weld, making formulæ more complex. For this reason we shall disregard the general case and deduce formulæ for only both extremes, viz., rigid encastrement and pin-jointed end.

To begin, let us regard the first case. In Fig. 7 nl is the length of weld. At this portion of the member the moment of inertia of the cross section is assumed to be equal to infinity (full rigidity). This being the only difference between Figs. 7 and 5, our deductions remain unaltered, except the limits of

integration. These will be now nl and $(l-nl)$ instead of o and l, respectively, as the rigid ends do not contribute to the work absorbed by the member. Thus we get in the place of equation (9)

$$\theta_2=\partial U/\partial M_e=(1/EI)\int_{nl}^{(1-n)l}\{M_e+(M_d-M_e)\,x/l\}\;\{1-x/l\}\,dx$$

$$=(l/6EI)\,[(1-6n^2+4n^3)\,M_d+(2-6n+6n^2-4n^3)\,M_e]$$

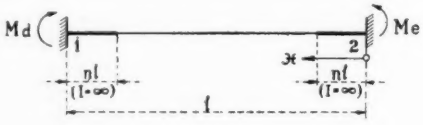

FIG. 7.

Since in the case of rigid encastrement there is no angular displacement at support 2, this expression may be put equal zero. Solving for M_e we get from above equation

$$M_e=-(1-6n^2+4n^3)\,M_d/(2-6n+6n^2-4n^3)=-\lambda M_d \qquad . \qquad (17)$$

It may be seen from equation (17) that in case of rigid encastrement the lowest theoretically possible value of the encastré moment is attained if $n=0$, *i.e.*, if the ends of the member are not rigid or not assumed so. In this case encastré moment is one-half the external moment. With growing length of weld encastré moment increases almost proportionally. It attains the value $-0.648\,M_d$ for $n=0.1$, *i.e.*, in case the rigid weld extends to 10 per cent. of the full length.

The moment curve is again a straight line, as shown in Fig. 8. Making

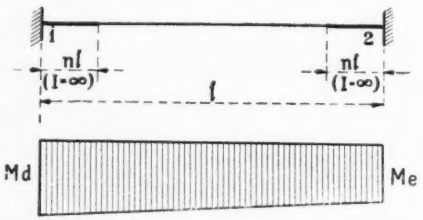

FIG. 8.

use of the First Theorem of Castigliano and putting

$$M_e=\lambda M_d$$

we get for the slope of the neutral line at support 1 :—

$$\theta_1=\partial U/\partial M_d=(1/EI)\int_{nl}^{(1-n)l}[\lambda M_d+\{(M_d-\lambda M_d)\,x/l\}]\,(x/l)\,dx$$

$$=(M_d l/6EI)\,[(2-6n+6n^2-4n^3)+\lambda\,(1-6n^2+4n^3)]$$

Re-writing equation (12) we have

$$\theta=Ml/fEI$$

and thus

$$f=6/\{(2-6n+6n^2-4n^3)+\lambda\,(1-6n^2+4n^3)\} \qquad . \qquad . \qquad (18)$$

Equation (18) in connection with equation (17) gives the value of the stiffness factor f when the member is rigidly encastred at support 2. In case it is pinned to this support we have $\lambda = 0$ and thus

$$f = 3/(1 - 3n + 3n^2 - 2n^3) \quad . \quad . \quad . \quad . \quad (18a)$$

Fig. 9 shows the stiffness factor f as plotted against the ratio of length of weld to full length of member (n). It may be seen from the diagram that stiffness of node is influenced considerably by the rigidity of weld. For simplicity we use

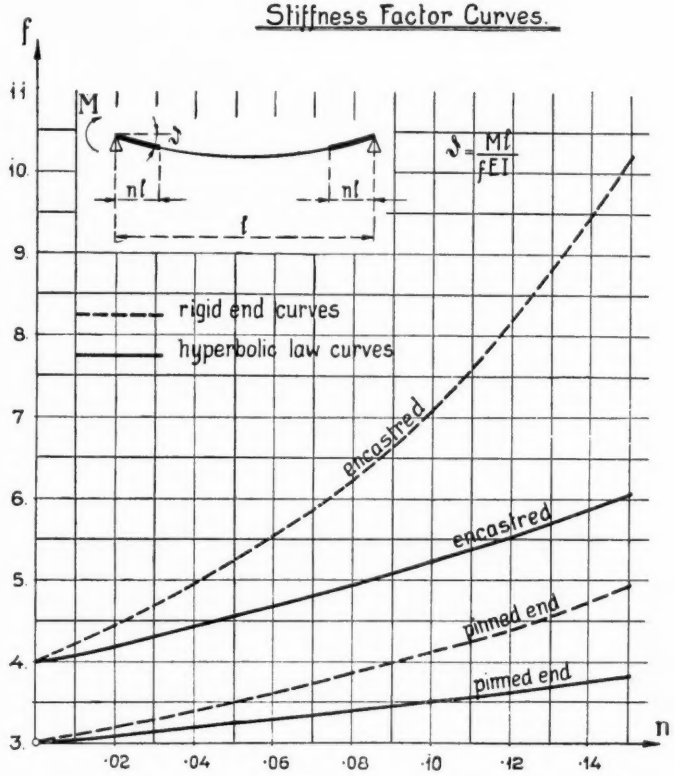

FIG. 9.

Fig. 9, jointly with Fig. 6. The difference between values of f as taken from curves relating to pinned and encastred ends, respectively, will be divided in the same ratio as shown in Fig. 6 for constant moment of inertia throughout. Values thus obtained are used for computing the magnitude of Φ and Ω.

The angular displacement of nodes calculated on this basis has been found smaller than twist obtained from experiments. This means that the assumption of perfect rigidity does not entirely hold for welds. For this reason we try to find a better approximation to fact. Obviously we should have a law for the

distribution of the moment of inertia along the welded portion of the member in consequence of which

(1) Nodes turn out less stiff than with the assumption of full rigidity of welds and
(2) Formulæ will have a simple form.

Assuming a hyperbolic law,* as shown in Fig. 10, we get a linear expression for the ratio M/I, if only

$$I_x = \{ 1/(1-n) \} (nl/x - n) I \quad . \quad . \quad . \quad . \quad (18b)$$

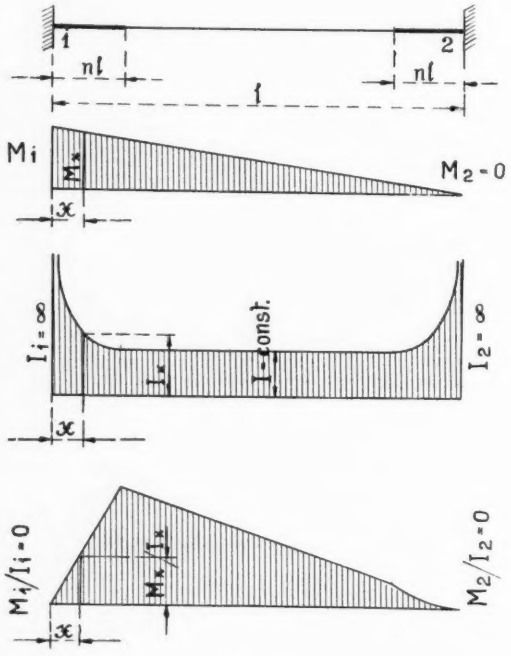

FIG. 10.

With this assumption the welded ends also contribute to the strain energy stored in the member. To get the new expressions for the angular displacements we have therefore to add this work to the strain energy calculated before. We omit here the somewhat lengthy and complicated calculations. They will be found in Appendix I. The results, however, being of use in the following paragraphs are given below:—

$$\lambda = (1-2n^2)/(2-3n+n^2) \quad . \quad . \quad . \quad . \quad (19)$$

By comparing equations (17) and (19) it will be noticed that the value of λ according to the hyperbolic law is approximately at midway between the original value, viz., 0.5, and the one obtained by assuming the welds rigid.

* Dr. Algyay-Hubert found the hyperbolic law to be in best agreement with experimental results when calculating secondary stresses of steel bridges. (See "Technika," February, 1934. Budapest.)

For the stiffness factor we get in case the other end of the member is rigidly encastred

$$f=6\,(2-3n+n^2)/\,\{\,(2-3n+n^2)^2-(1-2n^2)^2\,\} \quad . \quad . \quad (20)$$

and in case the other end is pin-jointed

$$f=6/(2-3n+n^2) \quad . \quad . \quad . \quad . \quad . \quad (20a)$$

These values of f are also plotted against n in Fig. 9 and may be used in the same way as outlined in the case of rigid welds. The angular displacement of nodes calculated in accordance with the assumption of a hyperbolic law has been found to be greater than that obtained from tests. Thus the actual value of f seems to be between the values arrived at using both assumptions.

Equations (20) and (20*a*) may be simplified by disregarding terms of higher than the first power of n. We get then

$$f=4+10\,n \text{ for encastred end} \quad . \quad . \quad . \quad . \quad (20b)$$

$$f=3+4.5\,n \text{ for pin-jointed end} \quad . \quad . \quad . \quad . \quad (20c)$$

This is, however, but a rude approximation.

Before concluding this paragraph it may be pointed out that in case of space frames twist of a node can be determined in like manner, but members will be subject to bending and also to torsion. The twist of a torded member, if encastred at the other end, may be written

$$\theta=Ml/NJ \quad . \quad . \quad . \quad . \quad . \quad (21)$$

where N is the shear modulus and J the polar moment of inertia of the cross section. In case of a circular steel tube N being equal 0.385 E and $J=2\,I$, we have

$$\theta=1.3\,Ml/EI \quad . \quad . \quad . \quad . \quad . \quad (21a)$$

By comparing this with equation (11*b*) we find that from our standpoint a round tube is

$$1.3\times 4=5.2$$

times less stiff against torsion than against bending.

§4. Torque Tests

In order to probe the methods evolved several tests have been carried out as stated already in §1. To this end two experimental girders have been constructed, resembling the side panels of an aeroplane fuselage.

Members have been made of low carbon steel tubes of circular cross section, joined by autogenous welding. Main dimensions may be seen from Figs. 11

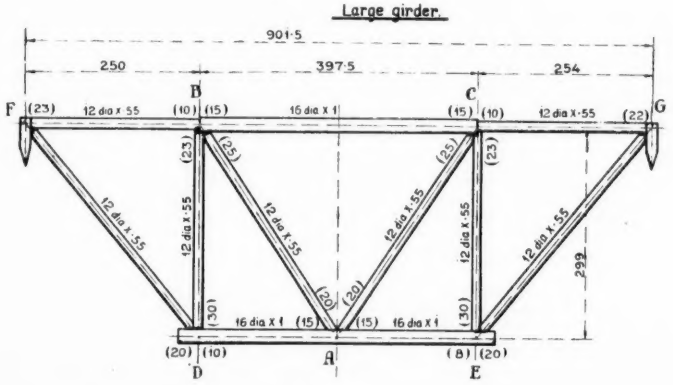

FIG. 11.

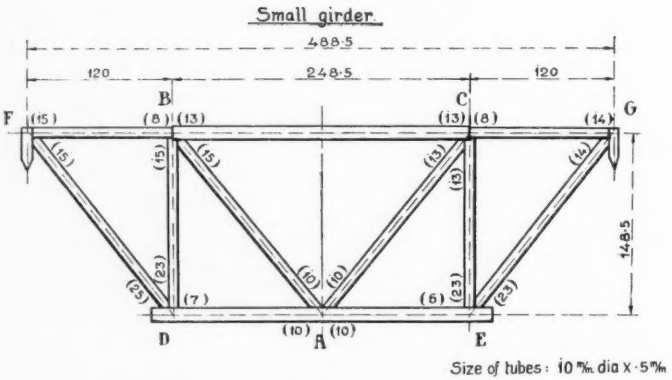

FIG. 12.

and 12, where lengths of members are given as measured between intersection points of centre lines. Lengths of welds are given in brackets. Tubes are denoted by outside diameter times wall thickness in millimetres, *e.g.*, 16 dia. by 1.

In this paragraph only torque tests are dealt with. Their aim is to find the relation of torque applied at a node of a frame to the distortion of the same, with a view to check results obtained in §3.

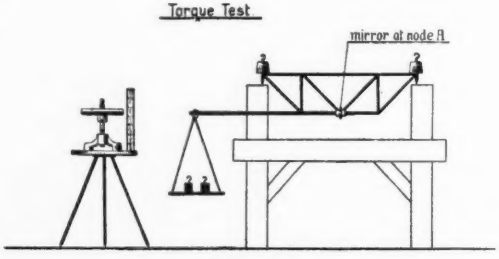

FIG. 13.

At node *A* (Figs. 11, 12 and 13) a fitting has been provided for a long lever the end of which has been loaded. On the other side of the frame, opposite the fitting strictly at the intersection point of centre lines a small tube carrying a small mirror has been welded at right angles to the plane of the frame. The angle of distortion of the mirror has been determined with aid of a scale with millimetre subdivisions, observed through a telescope. The difference between readings before and after loading is a measure of the angular displacement of the mirror and consequently of the node, due to loading. According to Fig. 14

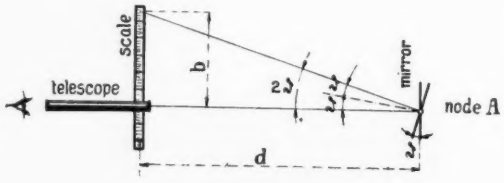

FIG. 14.

the twist may be calculated

$$b/d = tg\ 2\theta$$

and thus approximately

$$\theta = b/(2 \times d) \quad . \quad . \quad . \quad . \quad . \quad (22)$$

The frames shown by Figs. 11 and 12 consisted of small size tubes building girders of great height and therefore of great stiffness in comparison to the stiffness of members. Consequently it was permitted to neglect the angular displacement of the entire girder against the twist of the node. In the same way displacement of the girder due to bending could not be observed, since only the torque was large, but the weights applied were small (long lever).

The actual tests have been made by gradually loading and unloading the girders while simultaneous readings have been taken. These are tabulated in Tables I and II. From these it is evident that the whole investigation has been carried out within the limit of proportionality. Consequently results obtained by test are comparable with calculation.

Ends of the girder have been loaded to prevent lifting. Distortion of the girder as a whole being negligible this circumstance did not influence results.

In the tests described here the metric system has been used for lengths, weights, sizes of tubes, etc., consequently in tables and calculations the same system was adopted and only end results have been converted into British units.

§5. Comparison of Results obtained by Calculation and by Experiment. Torque

(*a*) *Large Girder.*

Readings have been collected in Table I. Average of these is

1.2 mm. displacement under a load of 1 kg.

Distance between mirror and scale being 1159.6 mm. we have in virtue of equation (22)

$$\theta = 1.2/(2 \times 1159.6) = 0.000517 \text{ (expressed in radians)}$$

or

$$\alpha = 57.3 \times 0.000517 = 0.0296 \text{ (expressed in degrees)}$$

Length of lever being 666 mm., the torque applied at node A is

$$1 \times 66.6 = 66.6 \text{ cm.-kg.}$$

Thus we get for the angular displacement Φ due to a unit moment applied at node A

$$\Phi = 0.000517/66.6 = 0.00000777 = 7.77 \times 10^{-6} \text{ radian per cm.-kg.}$$
$$\Phi = 8.95 \times 10^{-6} \text{ radian per in.-lb.}$$

Now we wish to compare this value with that computed according to equation (16). Length and size of the four tubes meeting at A are given by Fig. 11. The moment of inertia may be calculated or taken from a table. The ratio of the relative stiffnesses of nodes at both ends of members under consideration has to be estimated. Then the stiffness factor f follows by virtue of Fig. 6. Substituting these values in the right hand side expression of equation (16) we get Φ.

Since we purpose a close approximation to fact we have chosen the following way.

First of all the value of Φ has been computed for node A with the aid of a rough estimation of the ratios Φ_2/Φ_1. Then it was computed for nodes B, C, D and E. Having thus obtained as a first approximation the values of Φ for nodes A, B, C, D and E, a closer value of the ratios Φ_2/Φ_1 has been strived at for node A. These latter appear in the following table, in which only two tubes are represented on account of the symmetry of the girder. From these a second amended value of Φ was obtainable. In like manner may be arrived at subse-

quent approximations. This, however, was considered superfluous since even the second approximation differed but slightly from the first one. It may be remembered that connecting members with A have to be disregarded when calculating Φ of nodes B, C, D and E.

Tube	Length l cm.	I cm.^{4}	I/l	$\Phi_2/\Phi_1 = \Omega_2/\Omega_1$	f	fI/l
12 dia. × 0.55	35.8	0.0323	0.000903	3.5	3.5	0.00316
16 dia. × 1.0	19.9	0.133	0.00668	6.5	3.35	0.0224
						0.02556

$$\Sigma fI/l = 2 \times 0.02556 = 0.05112$$

Substituting in equation (16) we get with Young's modulus of elasticity of the value 2,100,000 kg. per sq. cm.

$$\Phi = 1/(2{,}100{,}000 \times 0.5112) = 9.32 \times 10^{-6} \text{ radian per cm.-kg. or}$$
$$\Phi = 10.73 \times 10^{-6} \text{ radian per in.-lb.}$$

This value is much in excess of that found experimentally, *i.e.*, the girder is much stiffer than calculated. To correct this we have to take into account the stiffness of welds, as explained in §3. As a first approximation there we assumed welds to be rigid. Since formulæ derived in §3 relate to members with equal length of welds at both ends, which is not the case with our girder, we take an intermediate length when determining the value of the stiffness factor. Since further the ordinate of the moment curve at node A is approximately twice that of the other end, it has a greater influence on the value f, and for this reason it would be an error to use the arithmetic mean of the length of welds. In the present case we suggest:—

Tube 16 dia. × 1, mean length of welds 12 mm., *i.e.*, 6.03 ≅ 6.1 per cent. of length of member.

Tube 12 dia. × 0.55, mean length of welds 22 mm., *i.e.*, 6.15 ≅ 6.1 per cent. of length of member.

From Fig. 9 we take the values of f for both cases pinned and encastred. These are 3.6 and 5.55 respectively. Calculating the actual value as outlined in §3 we get:—

Tube	I/l	f	fI/l
12 dia. × 0.55	0.000903	4.6	0.00416
16 dia. × 1	0.00668	4.3	0.0287
			0.03286

$$\Sigma fI/l = 2 \times 0.03286 = 0.06572$$
$$\Phi = 7.24 \times 10^{-6} \text{ radian per cm.-kg. or}$$
$$\Phi = 8.34 \times 10^{-6} \text{ radian per in.-lb.}$$

This value is closer to reality, but overestimates somewhat the stiffness of welds. For a second approximation we make use of the hyperbolic law.

Tube	I/l	f	fI/l
12 dia. × 0.55	0.000903	4	0.003612
16 dia. × 1	0.00668	3.8	0.0254
			0.029012

$$\Sigma fI/l = 2 \times 0.029012 = 0.058024$$
$$\Phi = 8.2 \times 10^{-6} \text{ radian per cm.-kg. or}$$
$$\Phi = 9.44 \times 10^{-6} \text{ radian per in.-lb.}$$

Here we attained a still closer approximation, but the stiffness of welds was underestimated. The actual stiffness of welds in the present case is therefore between the two values computed according to the two suggested laws.

(*b*) *Small Girder.*

Readings are tabulated in Table II. Average of these is
3.11 mm. displacement under 1 kg. load.
Distance between mirror and scale: 1,120 mm.

$$\theta = 3.11/(2 \times 1120) = 0.001388$$

Length of lever: 643 mm.

$$\Phi = 0.001388/64.3 = 2.16 \times 10^{-5} \text{ radian per cm.-kg.}$$
$$= 2.49 \times 10^{-5} \text{ radian per in.-lb.}$$

At node *A* four tubes meet. Lengths and sizes are shown in Fig. 12. Proceeding in the same manner as in the case of the large girder we get:—

(1) STIFFNESS OF WELDS NEGLECTED.

	Tube	l cm.	I cm.^{4}	I/l	Ω_2/Ω_1	f	fI/l
AC	10 dia. × 0.5	19.4	0.0169	0.000872	1.5	3.7	0.00322
AE	10 dia. × 0.5	12.4	0.0169	0.00136	2.5	3.6	0.00488

$\Phi = 2.94 \times 10^{-5}$ radian per cm.-kg. $= 3.38 \times 10^{-5}$ radian per in.-lb.

(2) WELDS ASSUMED RIGID.

Tube.	Mean length of weld. mm.	of weld. Per cent.	Stiffness factor f Pinned.	Encastré.	Actual.	I/l	fI/l
AC	11	5.67	3.55	5.45	4.9	0.000872	0.00427
AE	9	7.25	3.75	5.95	5.1	0.00136	0.00693

$\Phi = 2.12 \times 10^{-5}$ radian per cm.-kg. $= 2.44 \times 10^{-5}$ radian per in.-lb.

(3) STIFFNESS ASSUMED ACCORDING TO THE HYPERBOLIC LAW.

Tube.	Mean len of weld Per cent.	Stiffness factor f Pinned.	Encastré.	Actual.	I/l	fI/l
AC	5.67	3.3	4.65	4.25	0.000872	0.00371
AE	7.25	3.35	4.85	4.25	0.00136	0.00578

$\Phi = 2.5 \times 10^{-5}$ radian per cm.-kg. $= 2.88 \times 10^{-5}$ radian per in.-lb.

According to this test the assumption of rigidity of welds gives the closest, the hyperbolic law of stiffness distribution gives less and if the stiffness is entirely neglected the least approximation to reality.

§6. EFFECT OF STIFF WELDS ON END MOMENTS

It has been shown that the stiffness of welds influences a great deal the distortion of nodes and consequently the stiffness factor *f*. From this it follows that we have to investigate the effect of stiff welds on end moments. It will be seen that this influence is much smaller and it is even negligible if the maximum field moment alone be considered as it is sufficient for the purpose of stressing members.

In case of rigid welds we can make use of equations (1), (2) and (3). The limits of integration are now nl and $(1-n)\,l$ instead of 0 and l. Integrating as in §2 and substituting the new limits we get the following equations:—

$$\theta_1 = \partial U/\partial M_1 = (l/6EI)\,\{(2-6n+6n^2-4n^3)\,M_1 + (1-6n^2+4n^3)\,M_2 + [1-(l_2/l)^2-3n^2-2\,(l_1/l_2-1)\,n^3]\,Wl_2\} \quad . \quad . \quad (23)$$

$$\theta_2 = \partial U/\partial M_2 = (l/6EI)\,\{(1-6n^2+4n^3)\,M_1 + (2-6n+6n^2-4n^3)\,M_2 + [1-(l_1/l)^2-3n^2-2\,(l_2/l_1-1)\,n^3]\,Wl_1\} \quad . \quad . \quad (23a)$$

Equating the expressions obtained for θ_1 and θ_2 respectively with the right hand sides of equations (4) and (4*a*), further introducing the value of Ω as defined by equation (5) and rearranging we get

$$\phi_1 M_1 + \chi_1 M_2 = -\psi_1 Wl_2 \quad . \quad . \quad . \quad . \quad (24)$$
$$\phi_2 M_1 + \chi_2 M_2 = -\psi_2 Wl_1 \quad . \quad . \quad . \quad . \quad (24a)$$

where

$$\phi_1 = 2 + 6\Omega_1 - 6n + 6n^2 - 4n^3 \quad (25a)$$
$$\chi_1 = 1 - 6n^2 + 4n^3 \quad (25b)$$
$$\psi_1 = 1 - (l_2/l)^2 - 3n^2 - 2n^3\,(l_1/l_2 - 1) \quad (25c)$$
$$\phi_2 = 1 - 6n^2 + 4n^3 \quad (25d)$$
$$\chi_2 = 2 + 6\Omega_2 - 6n + 6n^2 - 4n^3 \quad (25e)$$
$$\psi_2 = 1 - (l_1/l)^2 - 3n^2 - 2n^3\,(l_2/l_1 - 1) \quad (25f)$$

In case of a hyperbolic law of variation of moment of inertia along the welded portion of the bended member expressions become too complex. We dissolve, therefore, the expression

$$(M^2/EI)\,dx$$

into the factors

$$(1/E)\,(M/I)\,M dx$$

and make use of the linear law for M/I. The product of both factors M and M/I is then to be integrated as it was done in Appendix II. Results obtained may again be expressed by equations (24) and (24*a*), the constants differing only :—

$$\phi_1 = 2 + 6\Omega_1 - 3n + n^2 \quad (26a)$$
$$\chi_1 = 1 - n^2 \quad (26b)$$
$$\psi_1 = 1 - (l_2/l)^2 - (\tfrac{1}{2})\,n^2 \quad (26c)$$
$$\phi_2 = 1 - n^2 \quad (26d)$$
$$\chi_2 = 2 + 6\Omega_2 - 3n + n^2 \quad (26e)$$
$$\psi_2 = 1 - (l_1/l)^2 - (\tfrac{1}{2})\,n^2 \quad (26f)$$

Since n is small, its third power may always and the second mostly be neglected. If we disregard all powers higher than the first of n, a very important simplification is possible. In this case it is suggested to subtract from Ω the value of n (rigid weld) or $n/2$ (hyperbolic law) and to make use of these corrected values of Ω when calculating end moments according to equation (7). If $\Omega_1 = \Omega_2$, equation (8) or Fig. 2 may be used. It is easy to prove that in case of unequal lengths of welds n_1 (or $n_1/2$) is to be subtracted from Ω_1 and n_2 (or $n_2/2$) from Ω_2.

§7. Bending Tests

Deductions made in §3 having already been verified by tests described in §4, it remains to check experimentally results obtained in §2. This is, of course, somewhat more difficult, because end moments cannot be measured directly. A linear and two angular displacements have been measured instead, viz., deflection of the loaded member at mid-beam and twist of the nodes at both ends. Corresponding values have also been calculated on the basis of our methods evolved in §§2, 6 and 8. The good agreement between results of calculation and experiment proves the closeness of our assumptions to reality.

For bending tests the same experimental girders have been used as described in §4. Member BC (Figs. 11, 12 and 15) was subjected to bending. At a point of one-third of its length the member was loaded by weights. Since member BC was welded to other members meeting at nodes B and C respectively, it was elastically encastred at both ends.

Deflections have been measured (Fig. 15) at mid-beam with aid of a worm-gear device having a dial divided into 1/100 mm. allowing an estimation 1/1000 mm. between. The twist of points B and C has been determined (Fig. 16) in the same way as described in §4. Two mirrors have been fixed at opposite sides of each node B and C at right angles to the plane of the frame. Simultaneously two readings have been taken using two telescopes and the average has been used for calculations.

Considering the far greater stiffness of the girder relative to that of member BC, linear displacements of nodes and angular displacements of members on account of primary stresses in members due to reactions of the external load have been beyond accuracy of measurement and negligible against distortions due to bending stresses. The whole displacement measured at mid-beam could therefore be regarded as deflection of member BC and the whole angular distortion measured at both ends of the member attributed to the twist of nodes B and C respectively.

During some of the tests ends (F and G) of the girder were loaded in order to ensure immobility of the system. In the readings no difference could be observed.

Some of the results have been collected in Tables III and IV. Measurements have again been taken during loading and unloading. The figures in the tables show that the whole investigation has been carried out within the limit of proportionality.

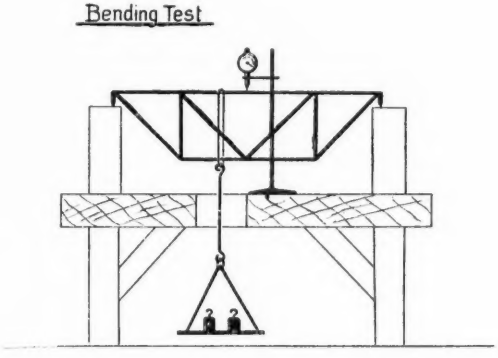

FIG. 15.

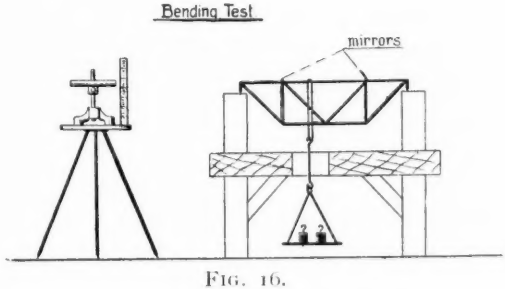

FIG. 16.

§8. COMPUTATION OF DISTORTIONS

(*a*) *Angle of Distortion of Support.*

Having estimated the stiffness of supports according to methods evolved in §3 and calculated end moments by formulæ given in §§2 and 6, the end distortion may easily be determined:—

$$\theta = \Phi M \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

(*b*) *Deflection at Mid-Beam.*

Deflection d at mid-beam under a load W at one-third of the beam has been calculated in Appendix III. Results of calculation are given here.

(1) Stiffness of welds neglected.

$$d=0.0177\,(Wl^3/EI)+0.625\,(M_1+M_2)\,l^2/EI \quad . \quad . \quad (27a)$$

(2) Welds assumed rigid.

$$d=(0.0177-0.166\,n^3)\,(Wl^3/EI)+(0.0625-0.25\,n^2)\,(M_1+M_2)\,l^2/EI \quad (27b)$$

(3) Stiffness assumed according to a hyperbolic law.

$$d=0.0177\,(Wl^3/EI)+(0.0625-0.0833\,n^2)\,(M_1+M_2)\,l^2/EI \quad . \quad (27c)$$

Note.—Formulæ are valid in both British and metric systems.

§9. Comparison of Results obtained by Calculation and by Experiment. Bending

(*a*) *Large Girder.*

(*A*) *Results of Experiment* (*Table III*).

(1) *Twist at Right End.*

Average of readings front: 0.202 mm. under 1 kg. load.

Distance between scale and mirror: 1271.6 mm.

$$\theta_f=0.202/(2\times 1271.6)=7.94\times 10^{-5}$$

Average of readings back: 0.213 mm. under 1 kg. load.

Distance between scale and mirror: 1275.6 mm.

$$\theta_b=0.213/(2\times 1275.6)=8.37\times 10^{-5}$$

Average:—

$$\theta_r=8.16\times 10^{-5} \text{ radian under 1 kg. load.}$$
$$=3.7\times 10^{-5} \text{ radian under 1lb. load.}$$

(2) *Twist at Left End.*

Average of readings: 0.285 mm. under 1 kg. load.

Distance between scale and mirror: 1109.6 mm.

$$\theta_l=0.285/(2\times 1109.6)=12.8\times 10^{-5} \text{ radian under 1 kg. load}$$
$$=5.82\times 10^{-5} \text{ radian under 1lb. load.}$$

(3) *Deflection at Mid-Beam.*

Average of deflections: 0.0206 mm. under 1 kg. load.
0.000368in. under 1lb. load.

(*B*) *Results of Calculation.*

(1) *Stiffness of Welds Neglected.*

First the relative stiffness factor has been determined. It has the same value for both ends in consequence of the symmetry of the girder. Calculation was made in the same manner as shown in §5 and thus presenting no further interest, it has been omitted.

We get for the angular displacement of node B due to a moment of 1 mkg., if stiffness of welds neglected

$$\Phi=81.5/E \text{ (expressed in radians)}$$

hence

$$\Omega=\Phi EI/l=(81.5\times 0.133)/39.75=0.272 \text{ (non-dimensional)}$$

By virtue of equation (8) we have

$$M_1=-(2/9)\,\{\,[2/3+(10/3)\times 0.272]/(1+8\times 0.272+12\times 0.272^2)\,\}\,Wl=-0.086\,Wl$$

With $W=1$ kg. and $l=39.75$ cm. we get

$$M_1=-0.086\times 1\times 39.75=-3.42 \text{ cm.-kg.}$$
$$M_2=-(2/9)\{[1/3+(8/3)\times 0.272]/4.07\}\,Wl=-0.0578\,Wl$$
$$M_2=-0.0578\times 1\times 39.75=-2.3 \text{ cm.-kg.}$$

The maximum free bending moment is

$$M_{\text{field}}=(l_1l_2/l)\,W=2/9\times 1\times 39.75=8.82 \text{ cm.-kg.}$$

With $W=1$lb. and $l=39.75$ cm. $=15.68$in. we get

$$M_1=-0.086\times 1\times 15.68=-1.35\text{in.-lb.}$$
$$M_2=-0.0578\times 1\times 15.68=-0.906\text{in.-lb.}$$
$$M_{\text{field}}=2/9\times 1\times 15.68=3.48\text{in.-lb.}$$

Displacements may be computed with aid of formulæ collected in §8. According to §8*a* we have

$$\theta_1=3.42\times 81.5/E=13.3\times 10^{-5} \text{ (radians)}$$
$$\theta_2=2.3\times 81.5/E=8.93\times 10^{-5} \text{ (radians)}$$

both under a load of 1 kg. and

$$\theta_1=6.03\times 10^{-5} \text{ (radians)}$$
$$\theta_2=4.05\times 10^{-5} \text{ (radians)}$$

under a load of 1lb.

In accordance with equation (27*a*) we get

$$d=[0.0177\times 1\times 39.75-0.0625\,(3.42+2.3)]\,(39.75^2/0.133\,E)=0.00198 \text{ cm.}$$
$$\text{if } W=1 \text{ kg.}$$

and

$$d=0.000354\text{in. if } W=1\text{lb.}$$

(2) *Effect of Stiff Welds.*

In the same manner displacements have been calculated for both cases when welds are assumed rigid and when stiffness of welds is assumed according to a hyperbolic law. Results are given in the following table. Here we find values of displacements by experiment and values of displacements of the "free" girder (no end moments).

Since this table serves only to compare results found by various formulæ, the values given in the metric system have not been converted into the British system.

(*C*) *Comparison of Results obtained by Calculation and by Experiments. Large Girder.*

	Ω	M_1 cm.-kg.	M_2 cm.-kg.	θ_1 radian	θ_r radian	d cm.
Stiffness neglected (calculated) ...	0.272	−3.42	−2.3	0.000133	0.0000893	0.00198
Hyperbolic law (calculated) ...	0.232	−3.73	−2.46	0.000123	0.0000810	0.00180
Rigid weld (calculated)	0.155	−4.38	−2.7	0.000097	0.0000597	0.00150
Results of experiment	—	—	—	0.000128	0.0000816	0.00206
Free girder (calculated) ...	—	—	—	0.000349	0.000279	0.00400

Note.—Calculated deflections do not contain displacements due to shear. This may be put approximately 0.00004 cm.

(*b*) *Small Girder.*

Calculations have been made in like manner as shown in the case of the large girder. Results are summarised in the following table:—

	Ω	M_1 cm.-kg.	M_2 cm.-kg.	θ_1 radian	θ_r radian	d cm.
Stiffness neglected (calculated) ...	0.0548	−3.13	−1.79	0.000120	0.0000687	0.00232
Hyperbolic law (calculated) ...	0.0448	−3.47	−1.84	0.000109	0.0000577	0.00191
Rigid weld (calculated)	0.0351	−3.77	−1.85	0.000093	0.0000457	0.00163
Results of experiment	—	—	—	0.0001183	0.0000566	0.00222
Free girder (calculated) ...	—	—	—	0.00107	0.000858	0.00763

Note.—Calculated values of deflections do not contain displacements due to shear. This may be put approximately 0.00008 cm.

(*c*) *Conclusions.*

Comparing results we find that displacements calculated on the assumption of a hyperbolic law for the moment of inertia of the cross section are in good agreement with displacements measured. Agreement is fairly good when stiffness of welds is neglected and not so good when welds are assumed rigid.

Calculated displacements of the free girder are also given in both tables.

From a comparison of all tabulated values we learn that the mean deviation of distortions computed with our formulæ based on the hyperbolic law from those measured amounts to 6 per cent., whereas distortions of the free girder used heretofore as the basis of the simplified calculation show an average deviation of 500 per cent.

Since in case of torque tests results were also in good agreement with the hyperbolic law and agreement was the worst when stiffness of welds was neglected, we may declare that the hyperbolic law represents best the actual properties of welds.

The calculation of end moments on this basis is rendered easy, when corrected values of the R.S.F. are used (see §6).

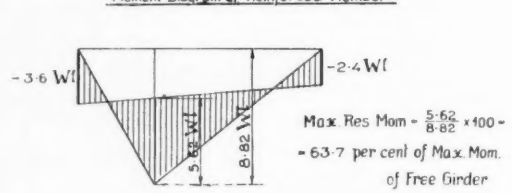

FIG. 17.

To show the effect on stressing of methods evolved moment diagrams of the loaded members of the experimental girders have been drawn in Figs. 17 and 18. It may be seen from these that maximum moment has been reduced by 36.3 per cent. in case of the large (reinforced) girder and by 39.2 per cent. in case of the small (normal) girder.

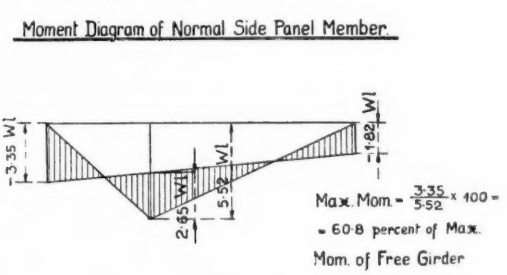

FIG. 18.

§10. FAILURE OF TRANSVERSELY LOADED MEMBERS

All our experiments so far described have been carried out within the limit of proportionality. The last experiment with the large girder has been extended beyond the yield point of the material.

The magnitude of the maximum resulting moment may be taken from Fig. 17.

$$M = 5.62\ W$$

when M expressed in cm.-kg. and W in kg. and

$$M = 2.21\ W$$

when M expressed in lb.-in. and W in lb.

The moment of inertia of the bended member being

$$I = 0.133 \text{ cm.}^4 = 0.00322 \text{ in.}^4$$

and the modulus of section

$$Z = 0.133/0.8 = 0.166 \text{ c.-cm.} = 0.0102 \text{ c.-in.}$$

we get for the bending stress

$$p = (5.62/0.166)\ W = 33.9\ W$$

when p expressed in kg. per sq.-cm. and W in kg.;

$$p = (2.21/0.0102)\ W = 217\ W$$

when p expressed in lb. per sq.-in. and W in lb.

The greatest load applied to the member was 190 kg. (=418lb.), consequently the greatest stress developed, supposing formulæ were valid

$p = 33.9 \times 190 = 6{,}440$ kg. per sq. cm. or
$p = 217 \times 418 = 90.700$lb. per sq. in. or
$p = 40.5$ tons per sq. in.

Simultaneously the stress at support 1 calculated with the same modulus of elasticity and the same moment of inertia, was

$p = 4{,}130$ kg. per sq. cm. or
$p = 26.0$ tons per sq. in.

Under this load the suspending wires of the scale-pan broke and thus the experiment could not be continued. The girder did not fail, but distortions began to increase rapidly.

Since a direct measurement of the ultimate tensile stress of the same tube unannealed gave a value of 5,500 kg. per sq. cm. and 4,000 kg. per sq. cm. when annealed, *i.e.*, 35 tons per sq. in. unannealed and 25.4 tons per sq. in. when annealed, it follows that the stresses obtained by calculation are too high.

The discrepancy between reality and calculation may be explained by analysing the phenomena after the yield point has been reached. At this point, in case of tough materials, strain may increase considerably without increase of

stress. Thus if the nature of the loading and of the encastrement corresponds to the moment line given in Fig. 18, or if ends of the bended member have in consequence of welding a lower yield point than the intact mid-portion, then in this case yield point will be reached first at one end and the member will get distorted more and more under an approximately constant end moment, if we continue loading. Simultaneously bending moment of the mid-portion grows more rapidly than before the yield point has been reached at the ends, viz., in the same proportion as in the case of a free girder, until yield will also here occur. Once the linear distribution of the stress has ceased the stress diagram will bulge out and bending formulæ lose their validity. Later on deflection at mid-beam may reach such magnitude, that part of the load will be balanced by pure tensile stresses as in the case of transversely loaded wires.

Whether or not this explanation be accepted we must make note of the fact that failure occurs under a greater load than according to formulæ, whereas elastic distortions show a good agreement with our calculations. A consequence of all this is that small errors in the determination of the R.S.F. can never cause a failure of a member if made of tough material, at worst only a lasting deformation. In view of the fact that the limit strength of aircraft, for which they are designed according to design requirements for aircraft for the R.A.F., is reached only in a few exceptional cases during their lifetime, the deformations mentioned above may occur very rarely, therefore fracture due to fatigue is not to be expected. Consequently members designed on these lines will be regarded safe without any additional safety factor.

§11. Axial Loads

During actual operation of an aircraft axial forces (tension or compression) are acting simultaneously with bending moments determined in our previous calculations. From stress calculation of spars it is known, that compression in a member increases the bending moment, while tension reduces it. Thus the slope θ at the end of a member will turn out greater than computed in §3, if the member is subject to simultaneous compression. The magnitude of this effect may easily be calculated if ends of members are supposed pin-jointed and stiffness of welds is neglected. For our purposes it is mostly sufficient to estimate the value of the stiffness factor f. It was found by theoretical considerations that this stiffness factor will be reduced from 3 to 2.5 when a compressive load equal to one-half of the Euler load is acting on the member supposing the member to be pin-jointed and stiff welds neglected. When the compression reaches the Euler load, we have $f=0$, *i.e.*, the member cannot exert any reaction moment, being itself laterally unstable. In actual calculations of Φ we have to make an allowance for this.

If the member on which the transverse load is acting is itself subject to end compression, it is mostly sufficient to calculate end moments with no regard to end loads. In order to get the maximum field moment we may make use of Perry's formula, as the bending line will always have two real points of contraflexure.

The approximation thus reached is, however, not very good, if both bending moment and end load (compression) are great.

§12. Summary

It has been shown in the preceding paragraphs how moment diagrams of transversely loaded elastically encastred girders of uniform cross section may be calculated. Some experiments on welded framework members have been described which showed good agreement with results obtained by calculation. Further experiments would be of great value to clear definitely the question of

distortion of members having stiff ends, especially in case of riveted or bolted girders.

For the purpose of stress calculation methods evolved are summarised below.

(*A*) *Determination of the Twist* Φ *of Support A due to a Unit Torque.*

(1) In case, when both ends of the bended girder are contained in nodes of a welded framework the following analytical method is to be used. If the

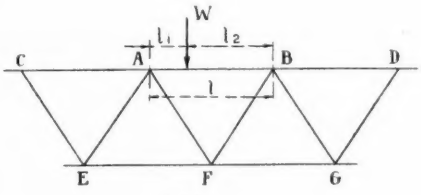

FIG. 19.

twist Φ of support A of member AB (Fig. 19) is to be determined we have to tabulate following values:—

Member.	Length l	Moment of Inertia of Cross Section I	I/l	Φ_2/Φ_1	f	fI/l
AC						
AE						
AF						
						$\Sigma fI/l$

In this table the first four columns will be filled up easily. A line has to be provided for every member meeting at A. The fifth column contains the ratios of the twist factors of both ends of a member, viz., Φ_C/Φ_A, Φ_E/Φ_A and Φ_F/Φ_A. The values Φ are, of course, not known, but after some experience their ratios may be estimated with sufficient accuracy in most cases. Otherwise the advice under (2) should be followed.

If we disregard the stiffness of ends of members values of the stiffness factor f should be taken from Fig. 6 where these are plotted against $\Phi_2/\Phi_1 = m$. Most frequently it is advisable to compute f according to (3).

In the last column we calculate the values fI/l. Their sum is to be used when computing the twist Φ of node A due to a unit moment

$$\Phi = 1/(E\Sigma fI/l)$$

(2) If for any reason a better approximation is wanted we may proceed as follows. We prepare tables as in (1) for nodes A, B, C, E and F, where for the ratios Φ_2/Φ_1 a rough estimation is sufficient. Values of f are calculated according to (1) or better according to (3). With aid of these tables we obtain values for Φ of nodes A, B, C, E and F in first approximation. Ratios of the latter are then used in a new table established for node A in order to get a better approximation for Φ_A.

(3) In case members are joined by relatively long welds their stiffening effect may not be neglected. In Fig. 9 values of f are plotted against the ratio n, *i.e.*, length of weld to full length of member. We make use of the " hyperbolic law " curves, those in best agreement with experiments. The difference of values taken from " pinned end " and " encastred end " curves must be multiplied by the difference: Stiffness factor obtained according to (1), less 3; this number is to be added to the stiffness factor of the pinned end curve.

(*B*) *Determination of the Relative Stiffness Factor.*

When Φ is known we get R.S.F. from equation (5):—

$$\Omega = \Phi EI/l$$

where E is Young's modulus of elasticity, I is the moment of inertia of the cross section and l the length of member AB.

(*C*) *Determination of End Moments.*

(1) If both ends A and B have the same R.S.F., end moments may be taken from Fig. 2.

(2) If the values of the R.S.F. at both ends are different we may still make use of Fig. 2, if taking for the R.S.F. a value between those obtained for both ends. It may be remembered that if the load acts near a support, the influence of the R.S.F. of the other end is small.

(3) In case of different end stiffnesses we obtain more accurate results when making use of equations (7) or (24) and (26).

(4) If members are joined by relatively long welds (or stiff riveted fish-plates) we may correct the R.S.F. obtained by subtracting from its value $n/2$, *i.e.*, one-half of the ratio of length of weld to length of member. The corrected value may be used for calculation of end moments according to equation (7), or in case of equal end constraint at both ends of the member, end moments may be taken from Fig. 2.

(*D*) *Determination of Maximum Bending Moment.*

We calculate maximum moment of the free girder

$$M_f = (l_1 l_2/l)\, W$$

When we set up end moments in the same direction as field moments of the free girder, supposing they are of opposite sign, we get the bending moment diagram of Fig. 20. The resulting moment at any point distant x from support 1 equals the length y of the shaded area.

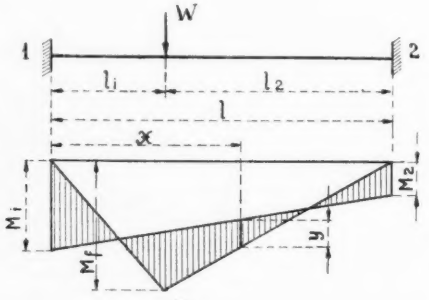

FIG. 20.

The greatest value of the resulting moment appears either at the point of application of the load, or at a support.

(*E*) *Application of the R.S.F. Method in Other Cases.*

(1) In case the members of the framework are not welded, but riveted and fish-plates used, by the R.S.F. method we get results in close accordance to reality.

(2) In case the bended girder is not a member of a framework this method may also be used, if Φ can be determined either experimentally or analytically.

Appendix I.

Determination of the Stiffness Factor f on the Assumption of a Hyperbolic Law for the Moment of Inertia

Be M_d the external moment acting at the left end on member 1-2 (Fig. 7). This will produce an encastré moment M_e at the right end. We obtain the angular displacement of the right end of the member if we imagine a unit moment at support 2 and calculate its work done when this member distorts under moments M_d and M_e.

The work done by unit moment M_u during displacement due to moment M_d may be written

$$U=(1/E)\int M_{xu}\,(M_{xd}/I)\,dx=(1/E)\int (M_{xu}/I)\,M_{xd}dx \qquad . \quad . \quad (20)$$

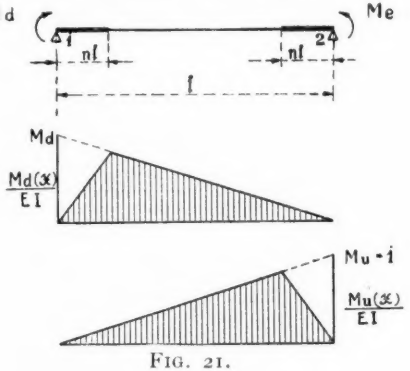

Fig. 21.

The product of corresponding ordinates of both diagrams of Fig. 21 equals $M_{xu}M_{xd}/I$, if a hyperbolic law is assumed according to Fig. 10. The integration of this product may be done easily since diagrams consist of straight lines only. *E.g.*, the product of both ordinates distant n from support 1 equals $[1-n]\,M_d n/I$. The value of the product at support 1 is zero. The curve of products between both values calculated is a parabola. The integral being equal to the area under the parabola we have

$$\int_0^{nl}(M_{xu}M_{xd}/EI)\,dx=(1-n)\,n^2lM_d/3EI$$

Proceeding in like manner we get

$$\theta_{12}=(M_d/EI)\,(l/6-n^2l/3)$$

The angular displacement at support 2 due to M_e may be calculated in like manner. The small curvature near support 1 may be neglected (Fig. 22). We get then

$$\theta_{22}=(M_e/EI)\,(l/3-nl/2+n^2l/6)$$

Assuming rigid encastrement at support 2 the sum of displacements due to M_d and M_e must equal zero. Hence

$$\theta_{12}+\theta_{22}=(l/6EI)\,[(1-2n^2)\,M_d+M_e\,(2-3n+n^2)]=0$$

and

$$M_e=-\,\{\,(1-2n^2)/(2-3n+n^2)\,\}\,M_d$$

or

$$\lambda=(1-2n^2)/(2-3n+n^2) \qquad . \quad . \quad . \quad . \quad (19)$$

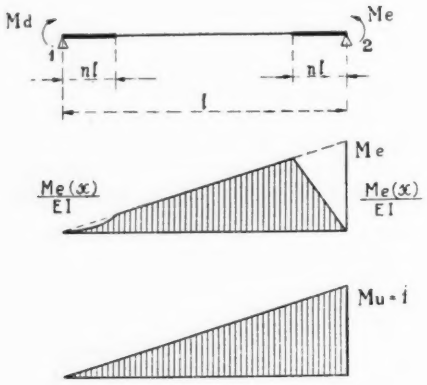

FIG. 22.

In consequence of the symmetry we obtain the angular displacement of support 1 by changing suffixes. Simultaneously substituting $M_e = -\lambda M_d$ we get

$$\theta_1 = (M_d l/6EI)\,[(2-3n+n^2)-\lambda\,(1-2n^2)]$$

With the value of λ as taken from equation (19) we have in case of rigid encastrement

$$f = 6\,(2-3n+n^2)/\,\{\,(2-3n+n^2)^2-(1-2n^2)^2\,\}$$

In case of pin-jointed end we get with $\lambda = 0$

$$f = 6/(2-3n+n^2)$$

APPENDIX II.

DETERMINATION OF END MOMENTS ON THE ASSUMPTION OF A HYPERBOLIC LAW FOR THE MOMENT OF INERTIA

This case differs from that dealt with in §6 inasmuch welds are not assumed rigid and contribute therefore to the strain energy stored in the members. Below we calculate only the portion of work stored in the welded ends, the rest having already been computed in §6.

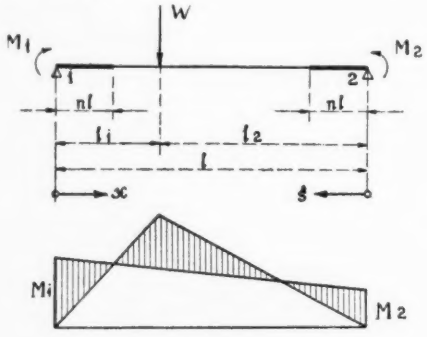

FIG. 23.

Fig. 23 shows the moment diagram of member 1-2. Re-writing equation (1) we have when $x < l_1$

$$M = M_1 + W\,(l_2/l)\,x + (M_2 - M_1)\,x/l \quad . \quad . \quad . \quad (1)$$

Assuming the length of welds smaller than the distance of the force from the support ($nl < l_1$) we may write

$$M/I_x = (1/I)\,[M_1\,(x/nl) + W\,(l_2/l)\,x + (M_2 - M_1)\,x/l] \quad . \quad (30)$$

M/I_x appears as a linear function* of x in concordance with proviso (2) § 3. Since I_x attains the constant value I at $x = nl$, the bracketed expression of equation (30) has the same value as the right hand side of equation (1) when $x = nl$.

The derivatives of above equations are

$$\partial M/\partial M_1 = 1 - x/l \quad . \quad . \quad . \quad . \quad . \quad (31)$$

$$\partial\,(M/I)/\partial M_1 = (1-n)\,x/nlI \quad . \quad . \quad . \quad . \quad (32)$$

The strain energy stored in the member between $x = 0$ and $x = nl$ is

$$\Delta U_1 = \int_0^{nl} (M^2/2EI)\,dx = (1/2E) \int_0^{nl} M\,(M/I)\,dx$$

The first partial differential coefficient of above expression with respect to M_1 is

$$\partial \Delta U_1/\partial M_1 = (1/2E) \int_0^{nl} [M\partial\,(M/I)/\partial M_1 + (M/I)\,(\partial M/\partial M_1)]\,dx \quad . \quad (33)$$

Substituting expressions of equations (1), (30), (31) and (32), integrating and rearranging, we get

$$\partial \Delta U_1/\partial M_1 = (l/12EI)\,[(6n - 10n^2 + 4n^3)\,M_1 + (5n^2 - 4n^3)\,M_2 + (5n^2 - 4n^3)\,Wl_2] \quad (34)$$

In like manner we get at the other end

$$M = M_2 + W\,(l_1/l)\,\xi - (M_2 - M_1)\xi/l \quad . \quad . \quad . \quad (1a)$$

when $\xi < l_2$

$$M/I_x = (1/I)\,[M_2\,(\xi/nl) + W\,(l_1/l)\,\xi - (M_2 - M_1)\,\xi/l] \quad . \quad . \quad (35)$$

Differentiating with regard to M_1, we get

$$\partial M/\partial M_1 = \xi/l$$
$$\partial\,(M/I)/\partial M_1 = \xi/lI$$

The partial differential coefficient of the strain energy stored in the right end of the member is therefore

$$\partial \Delta U_3/\partial M_1 = (l/12EI)\,[(5n^2 - 4n^3)\,M_2 + 4n^3 M_1 + 4n^3 Wl_1] \quad . \quad (36)$$

The twist of the left end of member 1-2 being equal to the partial differential coefficient of the total strain energy stored in the member (First Theorem of Castigliano) we have

$$\theta_1 = \partial \Delta U_1/\partial M_1 + \partial U/\partial M_1 + \partial \Delta U_2/\partial M_1$$

Substituting for the three terms expressions given by equations (34), (23) and (36) we get

$$\theta_1 = (l/12EI)\,[(4 - 6n + 2n^2)\,M_1 + (2 - 2n^2)\,M_2 + \{\,2 - 2\,(l_2/l)^2 - n^2\,\}\,Wl_2] \quad (37)$$

In like manner we get the twist of the right end of member 1-2

$$\theta_2 = (l/12EI)\,[(2 - 2n^2)\,M_1 + (4 - 6n + 2n^2)\,M_2 + \{\,2 - 2\,(l_1/l)^2 - n^2\,\}\,Wl_1] \quad (38)$$

* The law for the variation of I here used is not quite the same as given by equation (18b). Equation (30) has been chosen in order to get a linear law in case of a moment diagram according to Fig. 23.

In accordance with equations (4) and (5) we have

$$\theta_1 = (l/EI)\,\Omega_1 M_1$$
$$\theta_2 = (l/EI)\,\Omega_2 M_2$$

Equating both expressions of θ_1 and θ_2 respectively and rearranging we get equations (24) and (24*a*). Values of constants are given in equations (26*a-f*). Magnitude of end moments may be computed from the two linear equations.

Appendix III.

Determination of the Deflection

The deflection at mid-beam of an elastically encastred girder due to an external load applied at one-third of the beam equals numerically the work done by a unit force imagined at mid-beam during displacements caused by the external force. This work may be calculated in three portions, viz., the work done by the imaginary unit force during displacements of the free girder on two supports due to the external load and the two end moments separately.

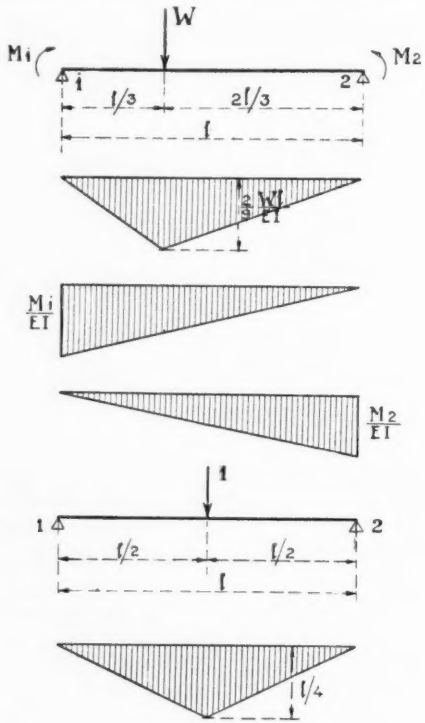

Fig. 24.

Moment diagrams are given in Fig. 24. With aid of the method applied in Appendix I we get

$$U_1 = (23/1296)\,(Wl^2/EI) \qquad U_2 = (1/16)\,(M_1 l/EI)$$
$$U_3 = (1/16)\,(M_2 l/EI)$$
$$d = (1/EI)\,[0.0177\,Wl^3 + 0.0625\,l^2\,(M_1 + M_2)] \quad . \quad . \quad (27a)$$

Assuming rigidity of welds ($I=\infty$) we have to subtract that part of the work, which has been stored in the welded ends of the member. This work may also be calculated in three portions:—

$$U_4=Wn^3l^3/6EI \qquad U_5=M_1n^2l^2/4EI$$
$$U_6=M_2n^2l^2/4EI$$

Subtracting the sum of U_4, U_5 and U_6 from the sum of U_1, U_2 and U_3, we get

$$d=(1/EI)\,[(0.0177-0.166\,n^3)\,Wl^3+(0.0625-0.25\,n^2)\,l^2\,(M_1+M_2)] \qquad (27b)$$

Assuming the hyperbolic law we get some additional terms corresponding to the work stored in the ends of the member. Moment diagrams are given in Fig. 25. They are similar to those described in Appendix I (Figs. 21 and 22).

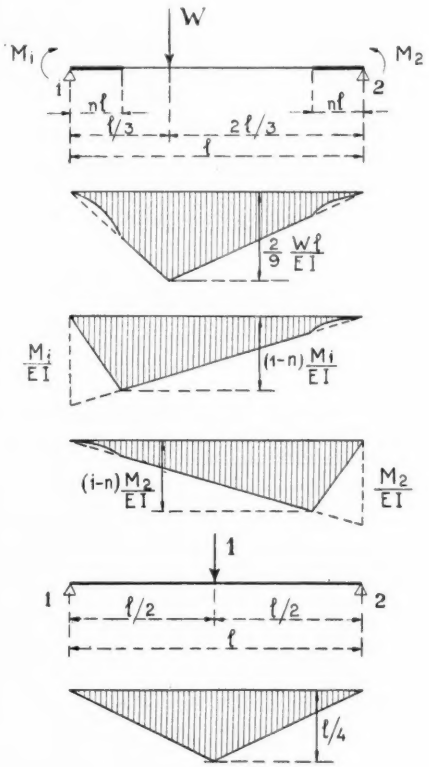

FIG. 25.

As may be seen the term with W will but very slightly differ from that obtained with aid of Fig. 24. We disregard this difference and compute only terms with M.

$$U_7=n^2l^2M_1/6EI \qquad U_8=n^2l^2M_2/6EI$$

Adding these terms to the right hand side of equation (27b), we get

$$d=(1/EI)\,[(0.0177\,Wl^3+(0.0625-0.0833\,n^2)\,l^2\,(M_1+M_2)] \quad . \qquad (27c)$$

TABLE I.

TORQUE TEST, LARGE GIRDER.

Length of lever, 666 mm.
Distance of mirror to scale, 1159.6 mm.

Loading. Weight. kg.	Readings in mm. 1st test.	2nd test.	Unloading. Weight. kg.	Readings in mm. 1st test.	2nd test.
0	0	0	7	8.45	8.35
1	1.2	1.2	6	7.2	7.2
2	2.4	2.4	5	6.0	6.0
3	3.7	3.65	4	4.9	4.8
4	4.9	4.75	3	3.75	3.65
5	6.05	6.0	2	2.45	2.4
6	7.25	7.2	1	1.2	1.2
7	8.45	8.35	0	0	0

Average: 1.2 mm. under 1 kg.

TABLE II.

TORQUE TEST, SMALL GIRDER.

Length of lever, 643 mm.
Distance of mirror to scale, 1120 mm.

Loading. Weight. kg.	Readings in mm. 1st test.	2nd test.	Unloading. Weight. kg.	Readings in mm. 1st test.	2nd test.
0	4.0	3.9	1.6	−1.1	−1.05
0.2	3.3	3.2	1.4	−0.4	−0.5
0.4	2.8	2.7	1.2	+0.2	+0.1
0.6	2.05	2.0	1.0	0.8	0.8
0.8	1.4	1.4	0.8	1.4	1.3
1.0	0.8	0.9	0.6	2.0	2.0
1.2	0.2	0.1	0.4	2.65	2.7
1.4	−0.4	−0.5	0.2	3.25	3.2
1.6	−1.0	−1.05	0	3.9	3.9

Average: 3.11 mm. under 1 kg.

TABLE III.

BENDING TEST, LARGE GIRDER.

1. *Deflection.*

Weights kg.	0	5	10	15	20	25	30	
Deflections	0.8	11.1	21.1	31.3	41.9	52.2	62.7	3rd test, loading
1/100 mm.	0.9	11.2	21.2	31.4	42.1	52.3	62.7	4th test, loading
	1.0	11.2	21.3	31.7	42.2	52.6	62.8	3rd test, unloading
	1.0	11.4	21.6	31.8	42.3	62.7	62.8	4th test, unloading

Average: 0.0206 mm. under 1 kg.

2. *Angle of Distortion, Right End.*

Distance of scale to front mirror, 1271.6 mm.
Distance of scale to back mirror, 1275.6 mm.

Weights kg.	0	10	20	30	40	
Readings	1.5	3.5	5.6	7.4	9.5	Front, loading
mm.	1.8	3.8	6.0	8.15	10.3	Back, loading
	1.3	3.2	5.3	7.3	9.5	Front, unloading
	1.75	3.8	6.0	8.15	10.3	Back, unloading

2nd test

Average front side: 0.202 mm. under 1 kg.
Average back side: 0.213 mm. under 1 kg.

3. *Angle of Distortion, Left End.*

Distance of scale to front mirror, 1109.6 mm.

Distance of scale to back mirror, 1109.6 mm.

Weights kg.	0	10	20	30	40		
Readings mm.	0	2.85	5.75	8.6	11.3	Front, loading	2nd test
	0	2.9	5.8	8.7	11.5	Back, loading	
	0	2.9	5.8	8.65	11.3	Front, unloading	
	0	2.95	5.85	8.75	11.5	Back, unloading	

Average: 0.285 mm. under 1 kg.

TABLE IV.

BENDING TEST, SMALL GIRDER.

1. *Deflection.*

Weights kg.	0	1	2	3	4	5	6	7	
Deflections	−1.2	0.8	3.1	5.5	7.7	9.7	12.1	14.3	2nd test, loading
1/100 mm.	−0.9	1.35	3.8	6.0	7.95	10.2	12.5	14.85	3rd test, loading
	−1.2	0.8	3.2	5.75	7.8	9.9	12.4	14.3	2nd test, unloading
	−0.8	1.9	3.9	6.05	8.1	10.4	12.8	14.85	3rd test, unloading

Average: 0.0222 mm. under 1 kg.

2. *Angle of Distortion, Right End.*

Distance of scale to front mirror, 1360 mm.

Distance of scale to back mirror, 1358.5 mm.

Weights kg.	0	5	10	5	0		
Readings mm.	−0.7	0.1	0.8	0.1	−0.8	Front side	1st test
	−1.2	−0.4	+0.3	−0.4	−1.25	Back side	
		Loading.		Unloading.			

Average front side: 0.155 mm. under 1 kg.

Average back side: 0.1525 mm. under 1 kg.

3. *Angle of Distortion, Left End.*

Distance of scale to front mirror, 1120 mm.

Distance of scale to back mirror, 1120 mm.

Weights kg.	0	5	10	5	0		
Readings mm.	0	1.4	2.7	1.4	0	Front side	1st test
	0	1.3	2.6	1.3	0	Back side	
		Loading.		Unloading.			

Average: 0.265 mm. under 1 kg.

TAPERED WING STALLING

BY

P. P. NAZIR, A.F.R.Ae.S., M.Inst.B.E.

It has been known for many years that the rectangular wing stalls first in the central region, burbling spreading gradually tipwards with further increase of incidence. This phenomenon is useful in connection with lateral control, because this control is retained for a while (though reduced) past the stall. Increased use of the tapered wing to-day raises the question of whether this phenomenon holds good with tapered wings. There is already some doubt on this score.*

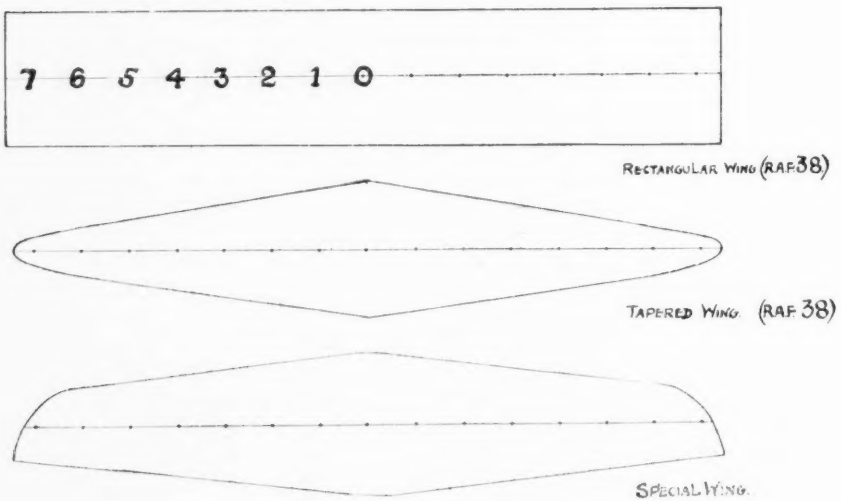

FIG. 1.

Plan forms of three aerofoils tested.
Dots indicate position of streamers along the span.

Another aspect of how burbling spreads along the span is in connection with re-distribution of load occurring near the stall. If the tapered wing behaves differently in this respect to the rectangular form, different strength calculations could be used in design.

An investigation was undertaken, ensuring comparative conditions. A rectangular and two tapered wings were included in the work. Fig. 1 shows plan forms of three aerofoils; the top one is rectangular and to R.A.F. 38 section,

* See an account of certain tests by Mr. Wenzienger, *Aeroplane*, 6th February, 1935.

the centre is heavily tapered and to the same section, and the bottom wing is moderately tapered and to another section. Tests were carried out at a speed of 42ft. per sec. in a 2ft. wind tunnel in the Aeronautical Department of Queen Mary College. The maximum chord of the aerofoils was 2.8in.

A simple type of streamer appeared suitable for observing the behaviour of each aerofoil. Special filaments of " swansdown " were attached to the upper surface by fixing each filament tightly in a hole of the size of the point of a needle. The streamers created negligible disturbance at small angles. Fifteen holes were drilled, one inch apart, along the span.

It was necessary to fix three or four filaments together for the purpose of taking photographs for demonstration. However, their behaviour was identical with that of the single filaments. The streamers were numbered as shown in Fig. 1. They were watched throughout the incidence range, and a record was made of those which became unsteady. The wings were tested for lift and drag through the incidence range, $-0°$ to $24°$, but visual tests were carried to much larger angles. From a great number of observations the following table was prepared :—

PERCENTAGE OF WING STALL AT VARIOUS INCIDENCES, FOR THREE DIFFERENT WINGS.

	Incidence.									
Type of Wing.	2°	4°	8°	11°	12°	13°	14°	16°	17°	18°
Rectangular—										
Per cent. wing stall	7	7	33	47	60	60	73	87	87	100
Tapered—										
Per cent. wing stall	13	27	40	67	80	93	93	93	100	100
Moderately tapered—										
Per cent. wing stall	13	13	40	73	73	80	80	100	100	100

It will be seen that the burbling area of the two tapered wings is double that of the rectangular wing at an angle of 2°. The quick spread of disturbance upon the sharply tapered wing can be seen clearly from the increase in the amount of area occupied at 4°, compared with the rectangular wing. This, however, did not occur in the case of the moderately tapered wing at 4° incidence, although it coincided again at 8° with the sharply tapered one. The distribution of stall is more interesting, however, than the amount of area occupied. This is shown in Fig. 2. Films were also taken which are described later.

It was found that all the streamers maintained a fairly steady position at zero degree incidence. The streamers No. 0 and No. 1 on each side of the rectangular wing gradually became unsteady with incidence increase. This unsteady motion of the streamers increased considerably at 9°, creeping towards the tips involving Nos. 0, 1, 2 and 3, on both sides. As incidence was still further increased to 12°, No. 4 streamer on each side joined in. This disturbance still further increased at 14° incidence involving No. 5 streamer, and affecting No. 6 and 16° incidence. A marked difference was observed in the case of the sharply tapered wing where No. 7 streamer on each side first became unsteady, and with further increase of incidence the burbling rapidly crept inwards. Streamers Nos. 7, 6 and 5, on each side were soon affected at 9° incidence, to which Nos. 4 and 3 joined at 11°. With the exception of the central streamer No. 0, all streamers appeared in a highly disturbed condition at 13° incidence. For the moderately tapered wing the growth of disturbance was different. No. 5 streamer on each side first became unsteady and burbling later spread both ways (outwards towards the tip, and also inwards towards the centre). With incidence at 11° Nos. 7, 6, 5, 4 and 3 streamers on each side all joined in the disturbance, and at 13° incidence streamer No. 2 was also affected.

α	Rectangular Wing.	Per cent wing stall	Tapered Wing.	Per cent wing stall
0°		0		0
2°		7		13
4°		7		27
6°		20		27
8°		33		40
10°		47		53
11°		47		67
12°		60		80
13°		60		93
14°		73		93
10°		87		93
17°		87		100

FIG. 2.

Showing burbling disturbance along the span of two wings:—
(1) Rectangular wing and (2) heavily tapered wing.
The percentage of area occupied by burbling is recorded in the neighbouring columns.

The following was observed of the tip streamers No. 7 in the case of the rectangular wing. Although the burbling gradually spread tipwards, and streamers even reversed their directions at 18°, streamer No. 7 at each tip did not appear to be as disturbed, nor did it reverse its position, through an incidence range of 75°. The last tip streamers on the tapered wing, on the other hand,

were unsteady and pointed towards the centre of the wing even at small incidences. As we have seen, this unsteady motion rapidly increased with small incidences and soon occupied a greater wing area creeping inwards, than that occupied in the case of the rectangular wing creeping outwards.

Some interesting directions of air flow were observed up to 75° incidence. A notable flow change took place at about 22½° incidence upon the rectangular wing. The flow which was almost reversed just before 22°, the streamers pointing towards the leading edge, now altered its course and started pointing towards each tip as illustrated in Fig. 3 (*a*). The streamers were almost parallel

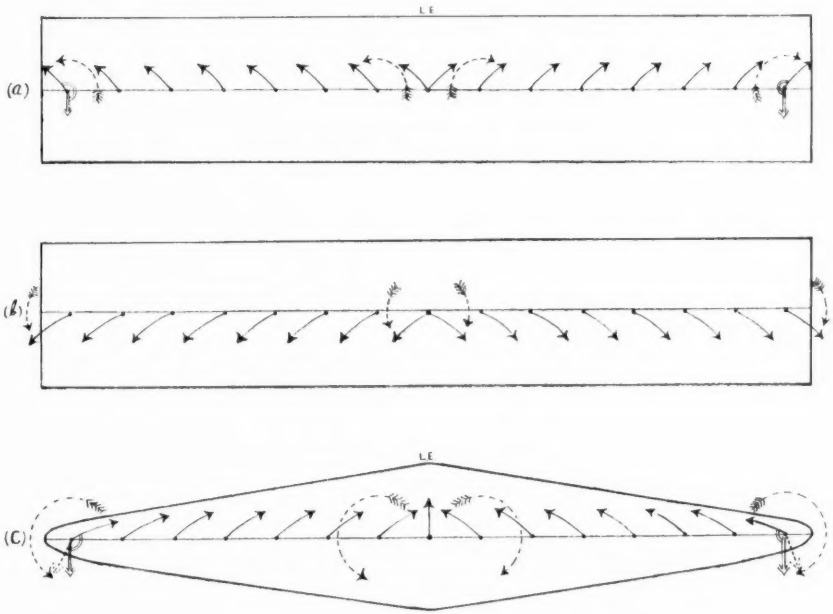

FIG. 3.

(*A*) *Showing airflow upon the rectangular wing, pointing forwards.*
(*B*) *Flow with same aerofoil, pointing backwards.*
(*C*) *Illustration of flow upon the tapered wing which creeps inwards first, and outwards later, until finally pointing backwards.*

to the wing span at about 27° and began to point backwards at 30°, Fig. 3 (*b*), until they completely pointed backwards at 75°. The last two streamers at each tip of this wing pointed backwards from 30° to 40°. It is possible that the straightening of the flow first begins at the tips, in the case of the rectangular wing, after the first complete stall.

In the case of the sharply tapered wing the flow began to be directed inwards at about 19°, as illustrated in Fig. 3 (*c*), in contrast with the rectangular wing. It again changed at 27° by spreading from the centre and pointing tipwards, as in the rectangular wing at 22°. Severe buffeting was observed developing upon the tips of the heavily tapered wing at 40° incidence. In the case of the medium tapered wing, the first flow appeared to change its course at about 20° pointing tipwards contrary to the sharply tapered wing.

An attempt was made to estimate the strength of disturbance by recording complete reversals of streamers. The first reversal of streamers occurred at 14° incidence with the rectangular wing, when nine streamers almost reversed simultaneously, and eleven were reversed completely at 18°. In the case of the tapered wing the two tip streamers almost reversed at 11°, then eight streamers at 14°, and fourteen streamers at 18° incidence, *i.e.*, all except the central one. Now considering the medium tapered wing, the first reversal occurred at 11½° incidence, when two intermediate streamers (third from each tip) completely reversed, as will also be seen in the film. With further increase of 14° incidence twelve streamers reversed, and all fifteen reversed at 18°.

The experiment shows that at low Reynolds number three different types of stall occur upon wings of different taper. The rectangular wing is subject to central stall, the medium tapered wing, to intermediate stall, and the sharply tapered wing, to tip stall. The central stall does not interfere with the control area till 14° incidence upon the rectangular wing. The tip stall begins directly upon the control area, and, contrary to the central stall, obviously affects control from the very beginning. The whole control area is rapidly occupied with an increase of 6° incidence only. The intermediate stall, which starts between the centre and the tip of the wing, partly occupies the control area at 4°, and with an increase at 10° affects the complete area.

Pigeon Wing

It was thought that the corresponding effects on a bird's wing would be interesting. A stuffed wing of a racing pigeon was tested up to an incidence of 50°. Some filaments of " swansdown " were attached to the upper surface of the wing in order to observe the flow. Incidence was measured from the centre section of the wing, and the central feathers being tied against deflection. Some photographs taken by the cinematograph show the type of burbling occurring upon the wing. The wing was 21in. span, × 4.5in. mean chord. The wall clearance in the wind tunnel was only 1½in. on each side, but the tip streamers appeared fairly steady at large incidences, when flow at the centre of span was severely disturbed. This may perhaps be due to the tips acting as a multi-slotted wing, or to incidence wash-out effect. The inboard thumb slot at 50 per cent. of the semi-span of the wing was fixed in its normal position during the tests. The wing was tested three times in the tunnel, and it was found that the lift was 5 per cent. less each time, although all curves were of similar shape. This appears to have been due to slackening of the stuffing every time lift was created upon the feathers. The drag was also measured.

Lift curves for all wings tested are plotted in Fig. 4. Great accuracy was not attempted, but the results are comparable with one another. The figure shows that the maximum lift of the rectangular wing occurs at 14° incidence, after which the lift falls off. In the case of the tapered wing the maximum lift occurs at a less angle, viz., 12° incidence, with a considerably steeper drop in lift. The drop in lift in the case of the moderately tapered wing, after the maximum lift at 11°, is of the same suddenness as that of the sharply tapered wing. There is a drop of about 19 per cent. at 22° incidence in the lift of the rectangular wing, and about 44 per cent. at same incidence of the tapered wing. Fig. 4 also shows the lift of the racing pigeon, as plotted against incidence. It will be seen that there is a gradual increase in lift up to 44° incidence, after which the lift very slightly falls off.

The Film

The first part of the film shows the rectangular wing gradually varied in incidence, and the effects upon the burbling as described are clearly seen by the

pointing of streamers in different directions. The central streamers point towards the leading edge showing the disturbance, while the outer ones maintain their backward direction to a considerable incidence. The second part of the film deals with the sharply tapered wing, where the outer streamers point towards the leading edge, contrary to the previous case, with central streamers fairly steady. The next part refers to the moderately tapered wing upon which the intermediate streamers (third from each tip) are seen reversing first.

Another film gives a slow motion picture of burbling, taken by a high speed camera, on all aerofoils, including the wing of the racing pigeon, kindly lent by the Royal Aeronautical Society for the purpose. The type of burbling upon the pigeon wing is of similar kind to that of the rectangular wing (*i.e.*, central stall) although the wing is moderately tapered.

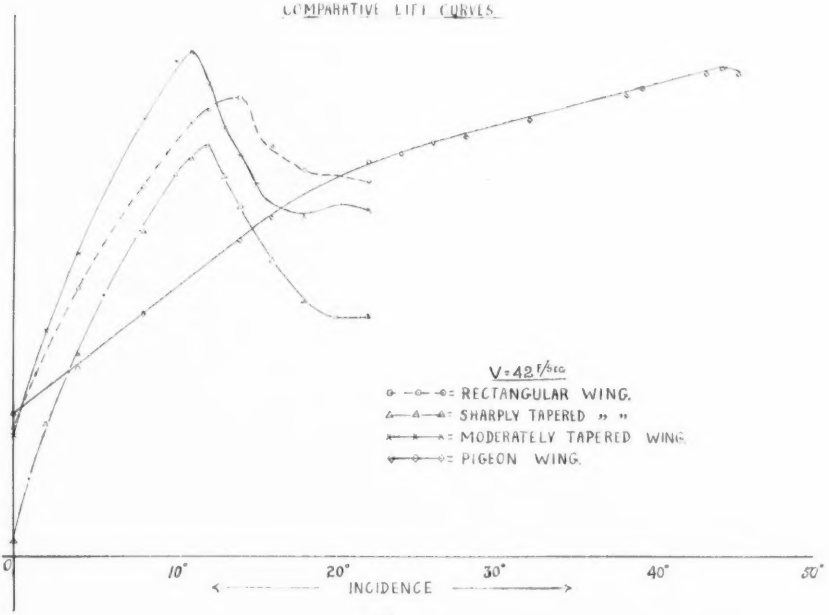

FIG. 4.

An attempt was made to record the flow changes at large incidences by the cinematograph, which will also be seen in the film. It is noticeable in the case of the tapered wing that all streamers then point to the tips.

Conclusions

Tests on aerofoils might well include a note of where stalling occurs along the span. A wing of fair taper might possibly be designed to stall first in the centre. Stalling phenomena bear a close relation to lateral control of aeroplanes and to strength considerations, and these experiments suggest that they are quite different for heavily tapered wings than for rectangular wings. Heavily tapered wings may encourage the stall, with a correspondingly steeper drop in lift.

The present results might well be compared with full scale by studying streamer movements in flight. Further, it might be investigated whether a similar effect occurs with very sharply tapered airscrew blades under climbing conditions.

I would express my grateful thanks to the High Commissioner and Government of India, whose financial assistance made this work possible, and to Dr. Piercy who directed the investigation to be carried out as a preliminary to other work on lateral control.

REVIEWS

The Air is Our Concern

Edited by Nigel Tangye. Published by Methuen and Co., London. Price 6/-.

The editor thinks that the publication of a book which would give the public an accurate view of current aviation problems is necessary; owing to the mass of ill-digested propaganda on this subject which is being printed in almost every newspaper. He has got together, therefore, a number of authors who are experts in various branches of aviation and has induced them to contribute chapters. Mr. C. G. Grey talks about the Development of Civil Aviation in Europe and about Air Transport of To-day, while American experience on this subject is contributed by Mr. Howard Mingos. Mr. Woods Humphrey deals with Imperial Airways, and Mr. C. E. Ward, Airports. Dr. Eckener talks about Airships, and the Editor himself about the North Atlantic Air Route. Professor Bairstow deals with Research; Group Captain Barton with Training Personnel; Mr. H. Balfour with Air Defence; and Air Commodore Chamier with Policing the Empire. The final chapter is Envoi by Prince Bibesco.

Mr. Nigel Tangye is to be congratulated on his list of contributors, among whom one is particularly pleased to see Professor Bairstow's name, and it is to be hoped that the book will have a ready sale among the general public, as it is important that they should have authoritative information. The author's article, in which he discusses floating islands in the Atlantic, contains, perhaps, rather more propaganda than is desirable in a book of this nature, for the practicability of the seadrome is so far improved and certain of his technical data is rather surprising to the engineer, but the book, generally, is one which should have a large circulation among those of the general public who want to understand rather than be entertained.

Aerodynamic Theory

Edited by W. F. Durand. Published by Julius Springer, Berlin. Price Rm. 20.

This is the third volume of the set of monographs on the general subject of aerodynamic theory published under the auspices of the Guggenheim Fund. It is in the English language in spite of the fact that it is published in Berlin.

This volume contains articles by C. Witoszynski and M. J. Thompson on Single Burbling; by L. Prandtl on the Mechanics of Viscous Fluids; by Professor G. I. Taylor and J. W. Maccol on the Mechanics of Compressible Fluids; and an article by A. A. Toussaint and E. Jacobs on Experimental Methods, in which much space is devoted to wind tunnels.

The names of the authors of the articles is sufficient guarantee of the quality of the matter they contain and it is not too much to say that the aeronautical community owe a great debt of gratitude to the Guggenheim Fund for the publication of these authoritative treatises. Nowhere else can the modern theory of aerodynamics be found so clearly explained and so well laid out for reference.

The Natural Logarithm

By Sir Charles Vernon Boys. Published by Wightman and Co., London. Price 2/-.

Sir Charles Boys, who is careful to insist that he is not a mathematician, had, he tells us, some difficulty in his younger days with Todhunter's account of the theory of logarithms, and has written this book with the view of assisting others who have had struggles with the ordinary proof.

As far as I know his method is novel, as it consists of a process of calculation which applies to a parabola and then correcting this for a hyperbola by means of certain correcting factors, and he succeeds in getting all the figures necessary for the calculation of a logarithm on to an ordinary postcard. The method is extremely ingenious and it is probable that it may be of considerable use to some, though I have myself had rather more difficulty with it than I had with the exponential method. It is fair to the author to state that he does not intend to supersede the normal method, but that he regards his process as being easier to understand. Although I do not agree with him, it is probable that many others will do so, and, in any case, the book is one which any student would be the better for reading. Facts are often clarified in the mind when they can be looked at independently from two very different angles.

Aerodynamik

Vol. II. R. Fuchs, L. Hopf and F. Seewald. J. Springer, Berlin. 30 Rm.

The first edition of this work was received with enthusiasm by all workers in aerodynamics and filled a long felt want, coming at a time when there were few up-to-date treatises in the subject. The recent advances in the science have been so manifold that in preparing a second edition, the authors have been compelled to sub-divide the subject matter. The volume under review deals with aerodynamic theory and is due to Fuchs alone. It commences with a chapter on the principal mathematical theorems to be employed, and then leads us rapidly on to the Joukowski aerofoil, the effect of a "ground," the "double-decker problem," and the aerofoil of finite aspect ratio. The theory of resistance is then fully treated, firstly, without viscosity and then with inclusion of this factor. Finally a useful statement of the present position of the turbulence problem both in relation to smooth and rough plates and tubes is appended.

No research worker, whether on the theoretical or practical side, of aerodynamics can afford to miss reading this volume.

CORRESPONDENCE

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

THE SOLUTION OF SIMULTANEOUS LINEAR EQUATIONS

Dear Sir,—

I was considerably interested in the method given by Captain Morris in the April number of the Journal for solving certain forms of simultaneous equations. The example worked out by the method shows a set of equations to which it is very applicable, namely, a set in which in the first equation the x term has a pronounced preponderance over the x terms in the other equations; in the second equation the same holds for the y term, and so on. In fact, the first equation may be looked upon as an equation which would give the value of x directly if it were not for the fact that this value has to have slight linear corrections for the values y, z and w. This, of course, is a type of equation which often occurs in physical calculations. I also understand that equations of this kind occur in the calculation of stresses in framed structures. In his approximations as tabulated it will be noted that after three cycles only of approximation, the values x, y, z are within 0.01 per cent. of their true values. Although so very useful in the above class of work the method is not nearly so useful for simultaneous equations in general, even though the condition for "convergency" may be satisfied, nor does Captain Morris claim this. For example, I tried a set of three equations in which the major terms were not quite so preponderant as in the example used by Captain Morris. These were:—

$$8x + y + 5z = 88 \quad . \quad . \quad . \quad . \quad . \quad (1)$$
$$x + 15y + 3z = 140 \quad . \quad . \quad . \quad . \quad . \quad (2)$$
$$5x + 6y + 10z = 182 \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The actual values of x, y and z are 2, 7 and 13 respectively. The progress of approximation in this case is as follows:—Not until after the seventh cycle of approximation do the values of y and z approach to within 0.1 per cent. of their true values; while the value of x after the seventh approximation is only within 1 per cent. of its true value, and would require many more cycles for it to approach to within 0.1 per cent. Each cycle of approximations occupies three lines. As a further example, I took the same three equations except that in equation (1) the coefficient of z was increased from 5 to 20 (and the constant term from 88 to 283). In this case, the first equation contains the predominant x term as well as the predominant z term, and it was found that the approximations became divergent, showing that the method is not applicable. For simultaneous equations in general containing three variables, the chance that the practical condition of applicability, as above stated, is seen to be 7 to 2 against. It will be seen that the practical condition as stated above for applicability ensures that each of the "ratios of distribution" shall be less than one.

The ordinary determinantal method of solving simultaneous equations, which is of course applicable in every case, is not however so formidable as might be imagined if, when evaluating the determinant, we use these two common properties of a determinant, viz.: (1) That the interchange of any two columns (or rows) simply changes the sign of the determinant; (2) that the subtraction of any multiple of the terms in any column (or row) from the corresponding terms in any other column (or row) does not alter the value of the determinant. By the use of these properties any determinant can be quickly altered so that every

figure in the first column except the top one is reduced to 0 and the determinant can then be reduced to one of smaller degree. This method has, I believe, been recommended by Mr. Chio, but I have not got the reference to his work.

As an example, take the set of three equations last considered, viz., equations (2) and (3) and the modified form of equation (1), *i.e.*,

$$8x + y + 20z = 283 \quad . \quad . \quad . \quad . \quad . \quad (1a)$$

The solution is

$$x/\Delta_x = -y/\Delta_y = z/\Delta_z = -1\Delta,$$

where Δ_x, Δ_y, Δ_z and Δ are the determinants obtained by striking out from the whole array of coefficients and final constants those columns containing the three final constants respectively, thus:—

$$\Delta_x = \begin{vmatrix} 1 & 20 & 283 \\ 15 & 3 & 146 \\ 6 & 10 & 182 \end{vmatrix} = \begin{vmatrix} 1 & 20 & 283 \\ 0 & 297 & 4099 \\ 0 & 110 & 1516 \end{vmatrix} \begin{matrix} \\ \ldots * \\ \ldots \dagger \end{matrix}$$

$$= \begin{vmatrix} 297 & 4099 \\ 110 & 1516 \end{vmatrix}$$

$$= -450252 + 450890$$
$$= 638$$

$$\Delta_y = \begin{vmatrix} 20 & 283 & 8 \\ 3 & 146 & 1 \\ 10 & 182 & 5 \end{vmatrix} = -1 \begin{vmatrix} 1 & 3 & 146 \\ 8 & 20 & 283 \\ 5 & 10 & 182 \end{vmatrix} = -1 \begin{vmatrix} 4 & 885 \\ 5 & 548 \end{vmatrix}$$

$$= 2192 - 4425$$
$$= -2233$$

$$\Delta_z = \begin{vmatrix} 283 & 8 & 1 \\ 146 & 1 & 15 \\ 182 & 5 & 6 \end{vmatrix} = \begin{vmatrix} 1 & 283 & 8 \\ 15 & 146 & 1 \\ 6 & 182 & 5 \end{vmatrix} = \begin{vmatrix} 1099 & 119 \\ 1516 & 43 \end{vmatrix}$$

$$= -176257 + 180404$$
$$= 4147$$

$$\Delta = \begin{vmatrix} 8 & 1 & 20 \\ 1 & 15 & 3 \\ 5 & 6 & 10 \end{vmatrix} = -1 \begin{vmatrix} 1 & 8 & 20 \\ 15 & 1 & 3 \\ 6 & 5 & 10 \end{vmatrix} = -1 \begin{vmatrix} 119 & 297 \\ 43 & 110 \end{vmatrix}$$

$$= -13090 + 12771$$
$$= -319$$

$\therefore\ x/638 = y/2233 = z/4147 = 1/319$

$\therefore\ x = 2,\ y = 7,\ z = 13.$

Yours, etc.,

T. W. K. CLARKE.

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* Formed by multiplying line 1 of the previous determinant by 15 and subtracting from line 2.

† Formed by multiplying line 1 of the previous determinant by 6 and subtracting from line 3.

The 588th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

A meeting of the Society was held in the Lecture Theatre of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2, on Friday, February 8th, 1935. In the chair: Mr. H. E. Wimperis (Director of Scientific Research, Air Ministry), Vice-President of the Society.

The CHAIRMAN: In the few minutes before the lecture would begin he would like to raise a point as to the hour of their meetings. He said that it was the practice of the Institution of Electrical Engineers, in whose building they were, as well as of the Institution of Civil Engineers and the Institution of Mechanical Engineers, to hold their meetings at 6 p.m., and asked for an expression of the wishes of the members of the Royal Aeronautical Society as to whether they would prefer the meetings of the Society to be held at that hour in the future, or would rather meet at 6.30 p.m., as heretofore.

The members present at the meeting indicated their wishes by a show of hands, and the voting appeared to be slightly in favour of meeting at 6 p.m. The Chairman intimated that he would mention the matter at the next Council meeting.

Calling upon Mr. W. C. Clothier to read his paper, the Chairman commented that ice formation was one of the troubles facing aircraft flying on every day in every weather, and one of the most troublesome parts on which the ice formed was the carburettor. Research had been directed to the subject at a good many places, the Royal Aircraft Establishment, at Farnborough, among them; Mr. Clothier had been a member of that staff for many years.

ICE FORMATION IN CARBURETTORS

BY

W. C. CLOTHIER, M.Sc., Wh.Sch., A.M.I.Mech.E.

PART I

GENERAL CONSIDERATIONS

From time to time we hear of mysterious engine failures, sometimes resulting in forced landings, in which the engine is reported to have gradually lost power until it was ticking over or had cut out completely. This may have been accompanied by sticking of the throttle, so that the pilot was unable to control his engine, and by rough running. Full power is usually recovered at lower altitudes or after landing, and when the engine is run up no defects can be discovered. At certain times of the year similar symptoms have been observed in the case of engines running on the test bed.

The troubles on the test bed have been shown to be due to the throttling effect of ice which has built up on the throttle butterfly or in the induction system. By quickly dismantling the carburettor this ice has been seen adhering to the throttle and to the walls of the induction pipe and on at least one occasion after the throttle had been jerked violently a piece of ice was thrown out of the exhaust

pipe. It is reasonable to suppose, therefore, that the flight troubles such as have been described, which disappear when the engine is tested on the ground and reappear at odd intervals in service, may be due to accumulation of ice in the induction system. Support is given to this supposition by the fact that such troubles are usually associated with humid days or flight near to or in cloud where conditions are favourable to the formation of ice.

During recent years, the general development of aircraft and improvements in air navigation have led to increased cloud flying and flying in weather conditions which would previously have been considered unsuitable and the number of failures or partial failures attributable to the accumulation of ice in the induction system has increased. Unless the pilot has had sufficient experience to recognise the symptoms, there has generally been little direct evidence to justify the conclusions that the cause of the trouble was carburettor freezing, as ice rapidly disappears on landing and the water that runs out of the air intake may easily be overlooked. It is possible, therefore, that some failures which have been caused by ice formation have been attributed to other causes. Hence it is important to understand the conditions under which dangerous ice accretion may occur in order that the trouble shall be avoided as far as possible, or in any case correctly diagnosed. It was with this object in view that the experimental work described in this paper was initiated.

Conditions for ice accretion

In this country the most likely cause of ice formation in carburettors is the cooling brought about by the evaporation of the fuel. A large quantity of heat is required to evaporate the fuel completely, and the heat for such evaporation as takes place before the mixture enters the cylinders is supplied by the air and by any part of the carburettor and induction system that may be in contact with the mixture stream. This cooling precipitates some of the water vapour that always forms part of the atmosphere if this water vapour is present in more than sufficient quantity to saturate the air at the final temperature reached by the mixture. If this temperature is below o°C. ice will be formed and some may adhere to the surfaces exposed to the mixture. Should the ice build up at a greater rate than it is broken away by the effect of vibration and the scrubbing of the air flow it will throttle the engine, causing loss of power and possibly other troubles such as bad distribution and rough running.

The humidity of the atmosphere is the most important factor in determining the severity of the ice formation that will occur with any particular fuel and engine installation and unfortunately there is a lack of information regarding the water content of the atmosphere at altitudes.

In this country near the ground the relative humidity is not likely to rise very far above 100 per cent. It has been estimated[1] that the water content of mist is 2 per cent. above saturation; of light rain 6 per cent., heavy rain 35 per cent., and excessive rain 80 per cent., the surplus being in the form of liquid drops. Thus 130 per cent. relative humidity might be considered a very severe condition near the ground as with heavy rain much of the water would never enter the air intake.

Under certain atmospheric conditions super-cooled water droplets may be present in the form of a cloud. When driven on to a surface at or near the air temperature, the water partially freezes, with an increase in temperature arising from the release of the latent heat of fusion. The unfrozen water will be blown away, leaving the ice on the surface. It is only occasionally that such conditions are encountered in this country and then not with great severity, but in other climates these conditions may cause ice to build up very rapidly. Besides accentuating the engine troubles now being considered, an accumulation of ice will occur on exposed surfaces of the aircraft, making flying difficult and, in extreme cases, impossible.

Supersaturation of the air with water vapour up to four times saturation is known to be possible when air is free from dust particles[2] which form condensation nuclei. A number of instances have occurred of aeroplanes causing cloud formation in a clear sky, and it seems probable that in these cases the air was supersaturated. Some measurements of the water content of the atmosphere using a method that allows readings over 100 per cent. relative humidity to be obtained, showed that occasionally values over 100 per cent. occurred at altitude. A belt of such air existed at 8,000 to 10,000ft. for several days (25th May to 31st May, 1933) in which the maximum relative humidity recorded was 127 per cent. These high humidities were usually obtained near but not necessarily in clouds. Sometimes over 100 per cent. was recorded in a clear sky. There is also a record[3] of a flight in Belgium where ice built up very rapidly at a height of 16,000ft.; in this case the relative humidity was estimated to be about 300 per cent., but it was not actually measured.

Supersaturation will increase the severity of the conditions, as far as the carburettor is concerned, but on account of the latent heat stored in the water vapour not to the degree that it would if the excess water were in liquid form.

When a temperature inversion exists in the atmosphere it may happen that rain will fall from a wet layer into a cooler and dryer layer. Undisturbed, the rain drops will evaporate slowly, cooling the atmosphere and the water, until equilibrium is reached. If the initial temperature is only slightly above freezing temperature the final temperature may quite easily be below freezing; this is probably one of the ways in which super-cooled water drops are formed. Any disturbance of the mixture of unsaturated air and water drops will hasten the heat exchange and ice will build up on the body causing the disturbance. Some meteorological conditions, when combined with the cooling due to the evaporation of the fuel, probably represent the most severe condition to which a carburettor is likely to be exposed. In flight it will be difficult to distinguish between the effects of super-cooled water drops and those caused by water droplets in unsaturated air, but because of the latent heat this latter condition will be the more severe. Expanding such a mixture, or even a mixture of water droplets in saturated air, past a throttle will cause further evaporation and ice will be deposited on the throttle if the temperatures are near 0°C. Tests with air flowing past a throttle in a glass tube showed that with intake temperatures up to +3 or +4°C. a fine spray of water drops would cause a rapid deposition of ice on the throttle.

Soft snow that tends to pack will be liable to block air intakes and build up in induction systems. As, however, the water is already frozen the extra cooling due to the fuel may possibly help by rendering the ice less liable to adhere to any surfaces that it may strike, but this is rather a matter for conjecture.

Freezing caused by the evaporation of the fuel

It will be useful to consider first the phenomena associated with evaporation of the fuel apart from the carburettor and induction system. If a spray of a volatile liquid is introduced into a stream of air the liquid will commence to evaporate and will draw the heat that it requires from itself, the air, and any surfaces with which it may come in contact. The liquid will continue to evaporate and cool the surroundings until the air is saturated with the vapour of the liquid or the whole of the liquid has evaporated. If the system receives no heat from outside, the final or saturation temperature will depend upon the intake air temperature, pressure and humidity, and the nature and temperature of the liquid, provided that there is sufficient liquid present to give saturation. Any heat that is received from outside the system will increase the final or saturation temperature and so increase the quantity of liquid that can evaporate.

It is necessary to consider how long it will be before approximate equilibrium is reached, as the time available in an induction system is short. An experiment

has been made with a spray of petrol introduced into a stream of air flowing along a pipe. Temperatures were measured by means of small bulb thermometers inserted into the air stream at different distances up to four feet from the point of entry of the petrol. By moving them across the pipe the quantity of petrol reaching the bulb could be varied and the minimum temperature measured. It was found that within close limits the same minimum temperature was recorded at all points. A thermocouple was held about a quarter of an inch from the point of entry of the petrol and even that recorded the same minimum temperature when moved across the mixture stream. The heat exchange is thus seen to be extremely rapid wherever the mixture is disturbed by an obstruction. Any body exposed to the mixture stream will reach this minimum temperature if it has the correct quantity of fuel sprayed on to it and receives no heat from outside.

Once the effects of pressure, humidity and fuel volatility on the saturation temperature are known, the measurements made by a thermometer exposed to the mixture stream and shielded from external sources of heat, may be used to predict the minimum temperatures that will be reached in a carburettor under

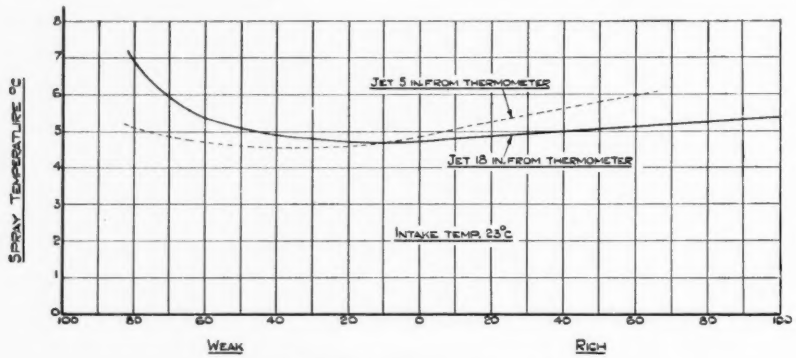

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FIG. 1.

Effect of mixture strength on spray temperature.

known conditions. The influence of the mixture ratio on the saturation or spray temperatures was studied by exposing a thermometer bulb to a petrol spray in a pipe along which air was flowing, and the ratio of petrol to air varied over a wide range. Tests were made with the thermometer at two distances from the point of entry of the petrol and the results are shown in Fig. 1, the spray temperature being plotted against mixture ratio. The thermometer bulb was in the centre of the air stream and the petrol was also introduced in the centre of the air stream. The mixture ratio is not that reaching the thermometer bulb, but the mean mixture; it is probable that the mixture in the vicinity of the thermometer was much richer. The tests show that over a wide range of mixtures the temperature of a body exposed to the mixture stream is relatively constant.

Effect of Pressure

Changing the pressure of the air will not alter the quantity of liquid required to saturate a given volume and so will not alter the quantity of heat that will be absorbed for a given final temperature, but it will alter the quantity of air to be

cooled proportionally with the absolute pressure. As the pressure is lowered therefore the saturation temperature will be lowered and for a given mass of air more liquid will be evaporated. It has been shown experimentally (4) that for a given final temperature the temperature drop is proportional, within close limits, to the absolute pressure of the air, provided no water is condensed.

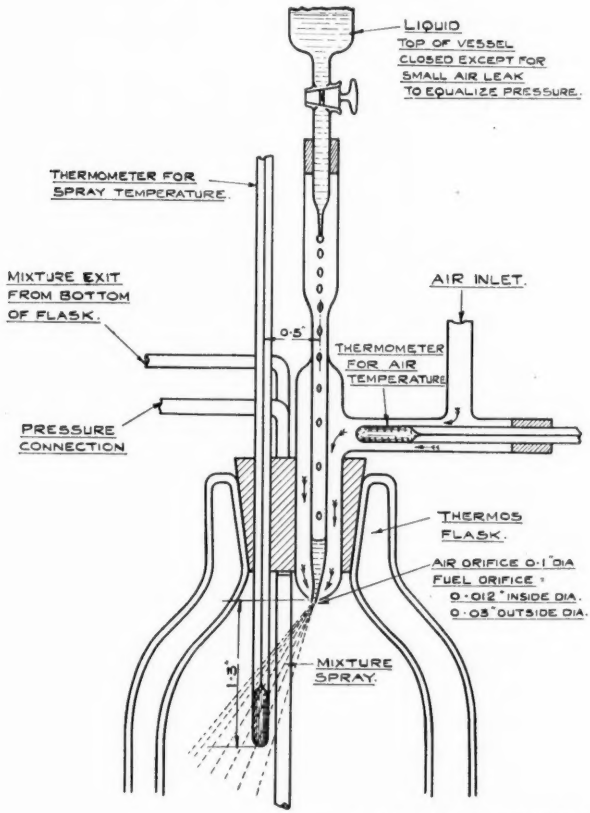

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FIG. 2.

Spray apparatus.

Effect of Humidity

Under normal atmospheric conditions some water vapour will be condensed by the cooling consequent upon the evaporation of the fuel and the latent heat of this water vapour will add to the heat available for evaporation. As sensible heat will be added to the system, the saturation temperature will increase, with the result that for a given intake air temperature more fuel will be evaporated with humid air than with air so dry that no water is condensed at the final temperature reached. Thus a greater temperature drop will be experienced on dry days than on wet days. Incidentally, this probably has some bearing on the supposedly better running of engines when the air is humid, as more fuel will

then be evaporated for the same intake temperature and better distribution may result.

Fuel Volatility

Fuels having different volatilities will vary in their liability to promote freezing and consideration has therefore been given[4] to the comparison of the volatility of fuels by measurements of the temperature reached by a body exposed to a spray of the fuel and air. To give as accurate a comparison as possible

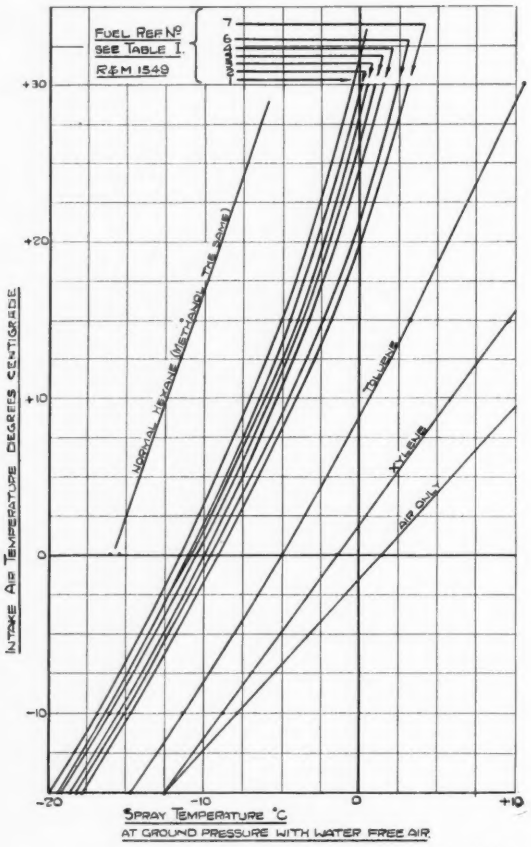

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FIG. 3.

Spray temperatures with various fuels.

between different fuels a laboratory apparatus was devised in which a mixture of fuel and air is sprayed on to the bulb of a thermometer under controlled conditions, the arrangement being such that the heat leakage into the system is small. The apparatus is illustrated in Fig. 2 and consists of a sprayer made of glass which directs a mixture of air and liquid on to the thermometer bulb. The sprayer and thermometer are both passed through the cork of a thermos flask, which

forms a convenient heat insulator. Two tubes are also passed through the cork, one to measure the pressure inside the flask and one to scavenge the mixture from the bottom. The rate of flow of the fuel is varied to give a minimum tempera-

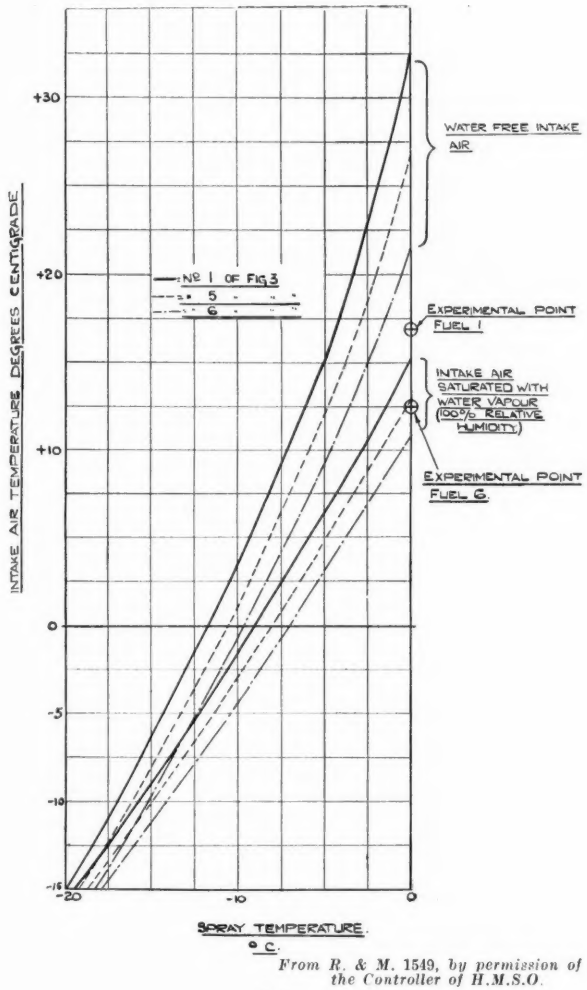

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FIG. 4.

Effect of water vapour on the temperature drop at ground pressure.

ture by means of the tap in the pipe from the reservoir. To provide standard conditions the air is dried to such a degree that no water will condense at the lowest temperature reached in the system.

Some results obtained by means of this apparatus are shown in Fig. 3. The fuels are all to specification D.T.D. 134 except Nos. 6 and 7. Fuels to D.T.D. 224 and 230 give comparable results. It will be seen that the fuels vary considerably in their volatility, and as even the most volatile is well below the limit of volatility set by the specification distillation range, a greater variation is possible. It has been shown[4] that these fuels are placed in the same order by the spray apparatus and the temperatures at which 5, 10 and 25 per cent. are distilled over, and that if the temperatures at which these quantities are distilled over are plotted against the air temperature for a spray temperature of 0°C. a relatively straight line results.

Thus it may be seen that the more volatile constituents have most influence in deciding the volatility of the fuel. It is suggested that the spray apparatus might well be used to compare fuels for easy starting properties as well as for freezing.

Judging from the distillation curves the fuels used in recent American experiments on carburettor freezing[5] are much more volatile than those used in the tests dealt with in this paper, and if the relation between distillation temperatures and spray temperatures is extrapolated, using the 10 per cent. point, their fuel D which is said to meet the minimum volatility requirement of a fighting grade aviation fuel, would require an air temperature of 37°C. to give a spray temperature of 0°C.

The spray apparatus has been used to determine the effect of humidity on the cooling due to the evaporation of the fuel. In Fig. 4, some of the curves of Fig. 3 have been re-plotted together with curves calculated for intake air saturated with water vapour. On these curves are marked points derived from experiments. It will be seen that the agreement is fairly good, but that the measurements give a greater drop in temperature than the calculations. This may be explained in two ways. It is possible that the air was not quite saturated although every precaution was taken to ensure this, or some degree of supersaturation may be necessary before the water is condensed. This latter explanation is considered the more probable and is in agreement with the results of the American experimenters,[5] who found that ice was only deposited from supersaturated air. A calculation has been made of the degree of supersaturation represented by this discrepancy in the temperatures, and at 0°C. it represents 22 per cent. relative humidity. The American experimenters concluded that freezing is probable with the temperature 4°C. below the dew point; for a final temperature of 0°C. this represents a relative humidity of 26 per cent. A higher value would be expected from the American results as they depended for their figures on visual observation of condensed water, whereas the spray test results do not.

At attempt has been made by the Americans to calculate the temperatures that will be experienced by a body exposed to a spray of liquid, based on the assumptions that thermal equilibrium would be reached by the time the spray reaches the body and that the mixture is homogeneous. They found that the calculated drop in temperature was generally less than the observed drop, but could advance no satisfactory explanation. It is thought that the explanation lies in their assumption that the mixture is homogeneous. Unless extreme precautions are taken to mix the air and fuel this is very improbable. As can be seen from their Fig. 11, the quantity of fuel that evaporates depends (for normal fuels) upon the mixture ratio; for example, their fuel D, at 0°C. with a mixture ratio of air to fuel of 12 : 1 evaporates 4.6 units of fuel, whereas a mixture of 6 : 1 evaporates 6.4 units, and 2 : 1 evaporates 10.5 units; therefore if the mixture is richer locally the evaporation will be increased and also the cooling. It was for this reason that in this present work no attempt was made to calculate the spray temperatures, but an apparatus for experimentally determining them was developed.

Conditions in a Carburettor

In most carburettors the fuel is emulsified by mixing with a little air and then mixed with the main air supply near the throat of the choke and at approximately atmospheric pressures sprays on to the throttle. At the throttle there is a rapid change of pressure (except at near full throttle) and the mixture passes into the induction system at high velocities.

The rapid expansion at the throttle causes a further cooling of the mixture, apart from the evaporation of the fuel, due to the adiabatic expansion of the air which may, if the pressure ratio is above the critical, give a reduction of tempera-

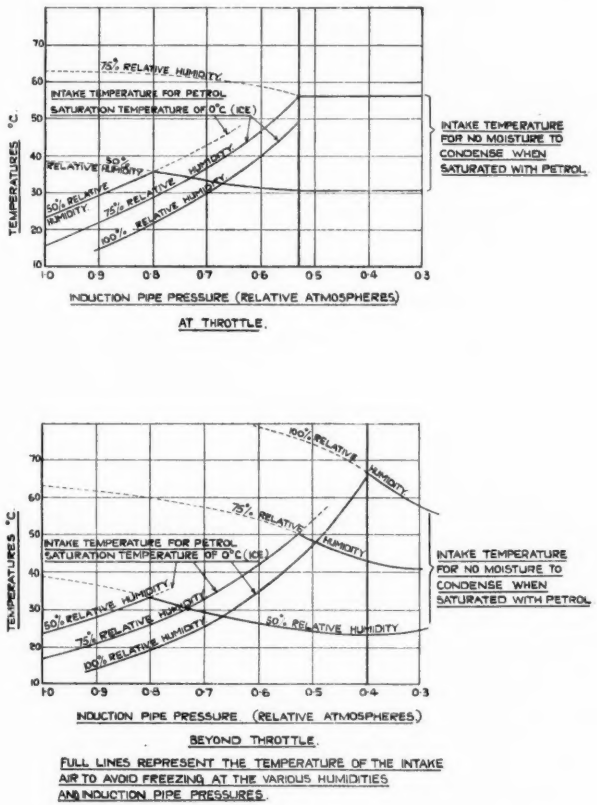

TEMPERATURES °C.
70
60
50
40
30
20
10
75% RELATIVE HUMIDITY.
INTAKE TEMPERATURE FOR PETROL
SATURATION TEMPERATURE OF 0°C (ICE)
50% RELATIVE HUMIDITY.
50% RELATIVE HUMIDITY.
75% RELATIVE HUMIDITY.
100% RELATIVE HUMIDITY.
INTAKE TEMPERATURE FOR NO MOISTURE TO CONDENSE WHEN SATURATED WITH PETROL.
1·0 0·9 0·8 0·7 0·6 0·5 0·4 0·3
INDUCTION PIPE PRESSURE (RELATIVE ATMOSPHERES)
AT THROTTLE.
TEMPERATURES °C.
100% RELATIVE HUMIDITY.
75% RELATIVE HUMIDITY.
INTAKE TEMPERATURE FOR PETROL
SATURATION TEMPERATURE OF 0°C (ICE)
50% RELATIVE HUMIDITY.
75% RELATIVE HUMIDITY.
100% RELATIVE HUMIDITY.
50% RELATIVE HUMIDITY
INTAKE TEMPERATURE FOR NO MOISTURE TO CONDENSE WHEN SATURATED WITH PETROL.
1·0 0·9 0·8 0·7 0·6 0·5 0·4 0·3
INDUCTION PIPE PRESSURE (RELATIVE ATMOSPHERES)
BEYOND THROTTLE.
FULL LINES REPRESENT THE TEMPERATURE OF THE INTAKE AIR TO AVOID FREEZING AT THE VARIOUS HUMIDITIES AND INDUCTION PIPE PRESSURES.

FIG. 5.

Heated intake air temperatures (from I.C.A.N. ground conditions).

ture of 48°C. This temperature drop, however, will not be experienced except to a small extent by any body exposed to the mixture stream and not moving with it, as to make contact with the body the air has to be brought to rest on the surface of the body and the kinetic energy turned into heat again. It has been shown by A. A. Griffith[4] that a drop in temperature of about one-eighth of the adiabatic drop will be recorded by a thermometer bulb. This figure has

been verified experimentally for a carburettor and will be referred to again. At the throttle, therefore, we may expect a further cooling of up to 6°C. which will disappear as the air slows up in the induction system beyond the throttle.

Assuming that no heat is gained by the carburettor, it is possible, therefore, to calculate the minimum temperature that can be reached by the various parts exposed to the mixture stream for an optimum mixture ratio. The value of such calculations is that they give an approximate picture of the way freezing is likely to vary with intake conditions and with altitude. Because of the number of variables it is difficult to present the results of such calculations concisely. A few calculations have been made using a method detailed elsewhere[4] and the results are shown in Figs. 5, 6 and 7. Two sets of lines are shown of which one set gives the heated intake air temperature for a saturation temperature of 0°C.

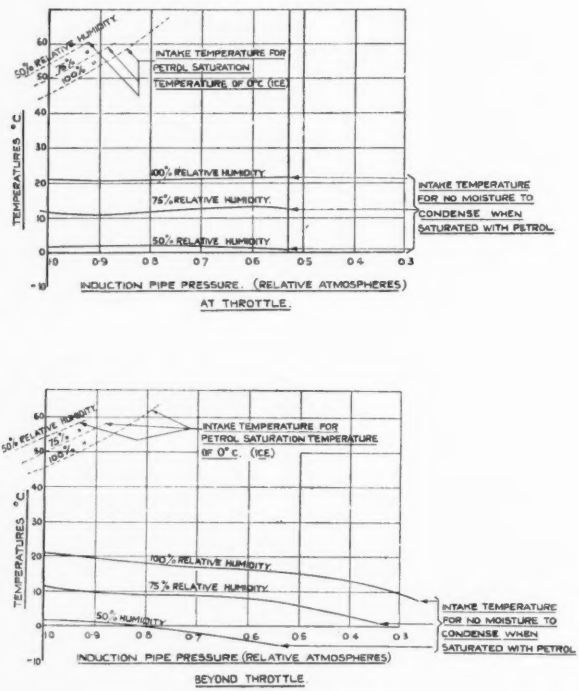


FIG. 6.

Heated intake air temperatures (from I.C.A.N. 10,000 *feet).*

(ice) and the other set gives the heated intake temperatures such that no water will condense. Below any pair of curves the temperatures are such that freezing may occur while above either curve the conditions are safe.

These results are based on the assumption that the water vapour condenses when saturation is reached and will require modification if it is assumed that some degree of supersaturation is necessary before the water condenses. The possibility of supersaturation was not considered to be sufficiently proved by the few tests made by means of the spray apparatus, but in view of the agreement between these tests and those of the Americans, some modification would seem

desirable. The dotted lines of Fig. 7 have been obtained by making the assumption that 4°C. of super-cooling is required before ice is formed.

From these calculations it appears that to prevent freezing entirely very large increases in intake air temperatures are at times necessary and that freezing is most likely to occur at altitudes below 10,000ft. To cover all the possible conditions many more calculations would be required. In these calculations no account is taken of heat leakage. Some consideration is given later in the paper, however, to the effect of heat reaching the carburettor from outside.

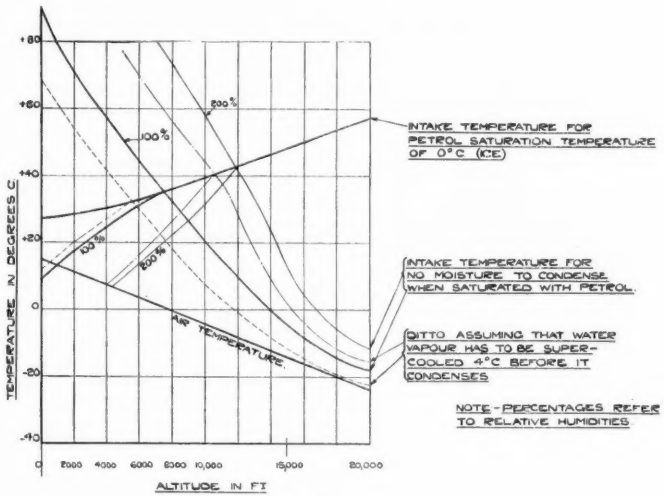


FIG. 7.

Heated intake temperatures from I.C.A.N. conditions, full throttle.

PART II

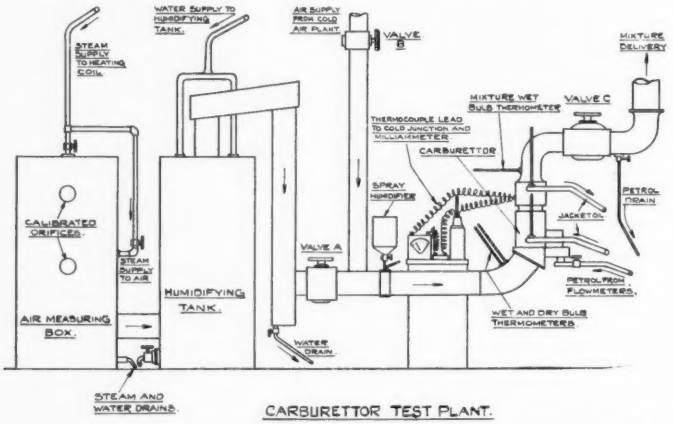
TEMPERATURE MEASUREMENTS IN A CARBURETTOR

While the foregoing analysis gives a picture of what occurs in a carburettor it neglects the heat leakage into the system, assumes that the mixture is ideal at all points and does not give any measure of the seriousness of such ice deposits as may be formed. Tests were therefore initiated to obtain data as to the temperature distribution in a carburettor, the way in which ice builds up and the degree of obstruction caused by such ice formations.

It is generally more convenient to make carburettor tests on some form of suction plant rather than on an engine, as this allows a greater range of conditions to be covered than is possible when the carburettor is part of an engine. The main differences between such tests and engine tests are the absence of heavy vibration, the failure of the suction plant to slow down, as the engine would, when the carburettor is throttled and for freezing tests the absence of engine heating by radiation and conduction. If engine test data are available the test plant may be adjusted to have engine characteristics as regards suction, but the effects of heat gained from the engine are far too complicated to be imitated on the test plant and are best studied by means of tests made on an engine.

Test plant

Before describing the tests which have been made it will be of interest to consider briefly the test plant used, Fig. 8 being a schematic view of the plant. The air flow may be measured by means of an air box fitted with sharp-edged orifice plates and the fuel flow by means of R.A.E. type fuel flow meters. These latter are not shown in the diagram. From the air box the air passes upwards through a humidifying tank in which it meets a spray of fine water drops from a number of jets. It was usually found possible to saturate the air by this means in the short time available while the air was passing through the tank. After the humidifying tank the air passes through a throttle valve A, for reducing the intake pressure, and along about 8ft. of straight pipe to the carburettor intake. At the T-connection, just after the valve, cold air can be supplied. Valve B enables the pressure and quantity of the cold air to be controlled and the quantity may be measured by the pressure drop along a calibrated length of the supply pipe. Any additional water required is added in the form of a fine spray of liquid drops by means of the sprayer shown just after the valve A.



CARBURETTOR TEST PLANT.

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FIG. 8.

Thus any water in excess of 100 per cent. relative humidity is in the form of liquid and not vapour. The temperature of the intake air could be raised by means of a steam coil inside the air box and if necessary steam could be admitted into the air to assist the humidifying tank.

The humidity of the air was measured by means of wet and dry bulb thermometers inserted in the air intake, the measurement being made before the water spray in the air intake was turned on. The quantity of water supplied by the sprayer was added to the humidity measurement to give the total water content of the air reaching the carburettor. The engine side of the carburettor was connected to a suction plant, the depression being controlled by means of the valve C. Hot oil was supplied when required to the carburettor heater jackets by means of a circulating pump provided with means for measuring the rate of flow of the oil and regulating the oil temperature. The oil temperatures were measured close to the carburettor oil inlet and outlet.

Description of the carburettor

A carburettor was available which had liberal oil jackets designed with a view to reducing the possibility of freezing. This carburettor, of the duplex

type, is shown in section in Fig. 9. It has a heater jacket surrounding the two chokes and throttle barrels and the jacket is extended in the form of a heater box some way up the delivery pipe. The twin exits from the chokes are combined on the delivery side to form one pipe in the heater box. The throttle butterflies themselves are unheated.

Thermocouples were inserted at various points as indicated in the illustration, Nos. 1, 2, 3, 5 and 6 were soldered into plugs screwed into the walls of the choke tube and heater box, the thermo junction being positioned about $\frac{1}{16}$ inch from the wall surface. Couple No. 4 was led in through the diffuser to a point in the emulsion tube exit. It was found possible to pass one thermocouple (No. 7) along the throttle spindle to the edge of the butterfly valve. A check

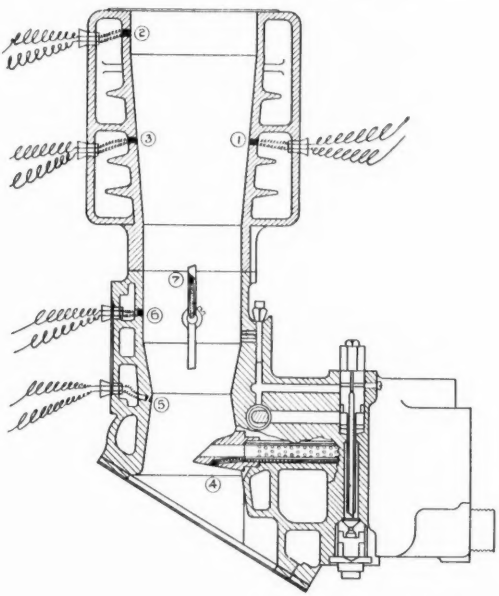

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FIG. 9.

Diagram of carburettor with thermocouples.

calibration was made after the thermocouples were in place by cooling the external junctions, the carburettor being at a uniform temperature. The mixture temperature after the carburettor was measured by means of a mercury thermometer in mid-stream, 2in. beyond the exit from the heater box.

As the carburettor was not of a standard pattern a calibration was undertaken before freezing tests were commenced. Measurements were also made of the pressure difference across the carburettor, over a range of intake densities, as this is an important factor in determining the quantity of fuel that evaporates. From these measurements it was concluded that the critical pressure ratio for this throttle agreed closely with the theoretical value of 0.53 and that for throttle opening less than 50°, the maximum air flow is not determined by the engine speed, that is if the throttle is less than one-third open no increase in air flow will result if the aircraft is turned into a dive from level flight, only the suction will increase.

Temperatures in an unheated carburettor

Air Flow Only

Temperature measurements were made with no fuel flowing to verify the accuracy of the prediction of A. A. Griffith that the cooling experienced by the throttle would be approximately one-eighth of the adiabatic cooling of the air passing the throttle. The tests were made with an intake air temperature of 20°C.

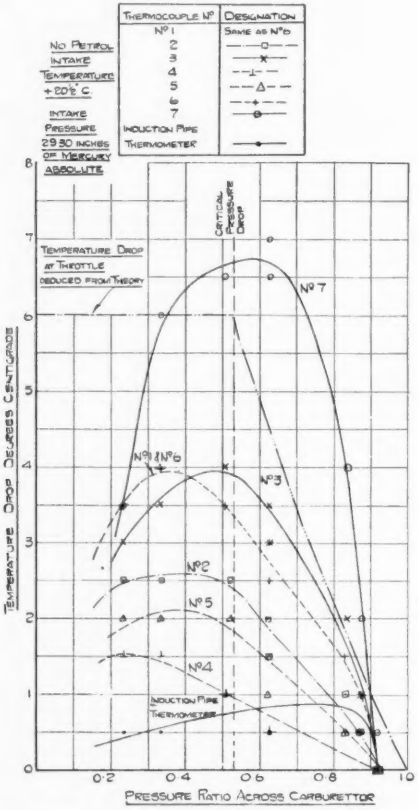

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FIG. 10.

and for this temperature the temperature drop at the critical pressure ratio should be 6°C. The results of the tests together with the calculated temperature differences are given in Fig. 10, and it will be seen that the agreement with the calculated values is very close, especially as the pressure ratios are based on induction pipe depressions and not on the actual pressure at the throttle. The decrease in the temperature differences at small throttle openings is due to heat leakage, the effect of which will be considered in more detail later. It is of interest to note how rapidly the air recovers its lost temperature; practically all the temperature drop has been recovered by the time the air reaches the induction thermometer, situated 2in. beyond the top of the heater box.

Heat Leakage

In an aircraft the air surrounding the carburettor will in general be considerably warmer than the air being drawn into the carburettor. Consequently there will be a flow of heat into the carburettor which will reduce the temperature drop due to the evaporation of the fuel. The influence of this heat leakage will increase as the air flow through the carburettor diminishes and the temperature drop will therefore decrease with decreased air flow.

When supplying the carburettor with cold air on the test plant similar leakage will occur, and some measure of this is given by the results plotted in Fig. 11, which shows the temperature distribution when air only is drawn through the carburettor. As would be expected, the heat leakage has the least effect on

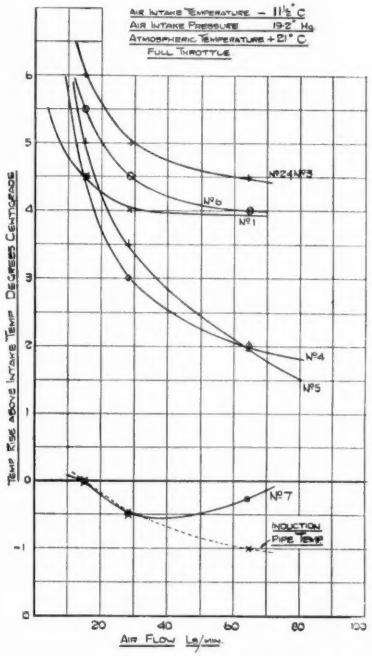

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FIG. 11.

the throttle butterfly, emulsion tube and choke. In spite of the large difference in temperature between the inside and outside (32°C.) the heat imparted to the air is negligible, in fact, due to some small error, the measurement gave a negative gain.

With Air and Fuel Flows

Before making a number of measurements it was thought advisable to check that the mixture ratio was only of secondary importance and tests were made at half throttle with an intake air temperature of 12°C. in which temperatures were measured with the mixture varied from 22 per cent. rich to 31 per cent. weak. The change of temperature was found to be negligible. The fuel used during these and all other carburettor tests, unless otherwise specified, was similar to fuel No. 5 of Fig. 3 and to specification D.T.D. 134.

In Fig. 12 the temperatures recorded at the different points are shown for the throttle range, the air flow being that for level flight. The temperature at points 1, 2 and 3 follow each other closely, 1 and 3 being closer to the throttle are more affected by the adiabatic temperature drop and consequently colder than 2. At small throttle openings the lowest temperature is recorded by the

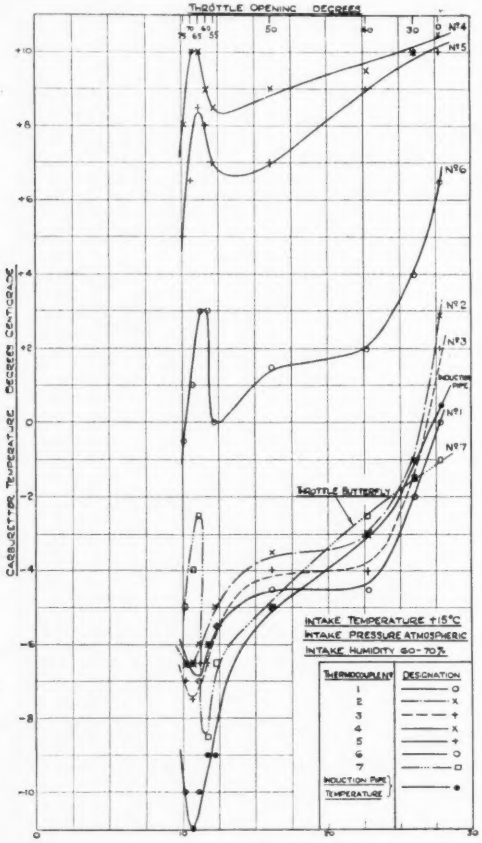

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FIG. 12.

induction pipe thermometer, probably because this thermometer is least affected by heat leakage. The kink that occurs in all the curves at about 65° throttle is due to the influence of the slow running jets. As the throttle is closed the flow from the slow running jets increases and at about 60° throttle the main jets go out of action. Most of the petrol then misses the throttle butterfly with the result that while the temperatures beyond the throttle fall owing to the increasing suction, the temperatures of the throttle and points before the throttle rise owing to reduced evaporation from these points. So points 1, 2 and 3 and induction pipe fall and 4, 5, 6 and 7 rise. As the throttle is closed further, there comes a position at about 70° where the flow from the slow running jets impinges on the throttle butterfly and the parts which follow the throttle are cooled again.

The results shown in the figure are typical of those occurring at other intake temperatures. At reduced intake pressures a larger proportion of the petrol is evaporated at or near the throttle and the throttle and associated temperatures are reduced while the heater box and induction temperatures may be raised by the heat conduction. The lowest temperature always occurs at or beyond the throttle according to the intake conditions and throttle position. Changes of intake temperature only affect the position of the coldest temperature through their effect on the heat leakage. At full throttle the heater box is warmer than the throttle, as the wetting of the walls by the mixture is small. With longer induction systems or at bends or elbows where the petrol is thrown on to the walls the temperature will be much the same as those of the throttle provided there is no heating of the walls. As the throttle is closed the mixture is deflected

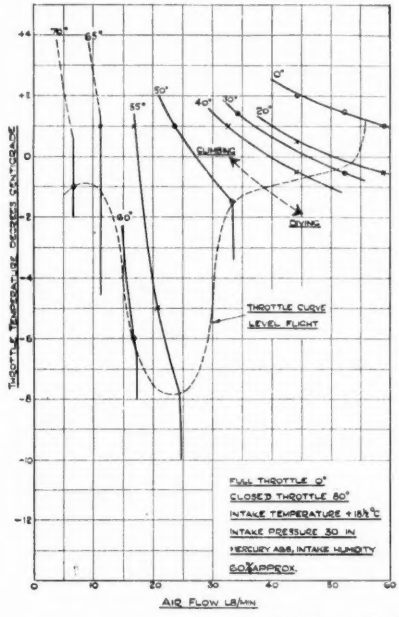

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FIG. 13.

on to the walls of the heater box which will be then as cold as the throttle and ultimately become colder. Beyond this it does not appear possible to locate accurately the coldest parts of a carburettor, but it may be assumed that wherever a stream of mixture impinges, there cooling will occur.

Effect of Attitude of the Aircraft

As the aircraft goes into a climb from level flight the engine speed falls, and the depression in the induction pipe is reduced, similarly on the dive the depression increases. In Fig. 13 are plotted the temperature variations for various fixed throttle positions over a range of induction pressures. To simplify the result only the throttle temperatures are given, as in general that is the lowest temperature and is thought to have a considerable influence on freezing, at any rate as far as low altitudes and high humidities are concerned. Each power

curve (fixed throttle varying air flow) is intersected by the throttle curve at a point representing level flight. To the right and below this point the curve refers to diving flight; to the left and above it refers to climbing flight. It is evident that the more the aircraft is dived the lower the throttle temperatures. The power curves at throttle openings of 50° and less are limited by the effects of the critical pressure ratio across the carburettor so that when diving a further temperature drop occurs without increase of air flow. The position of the throttle curve is not definitely known at small throttle openings.

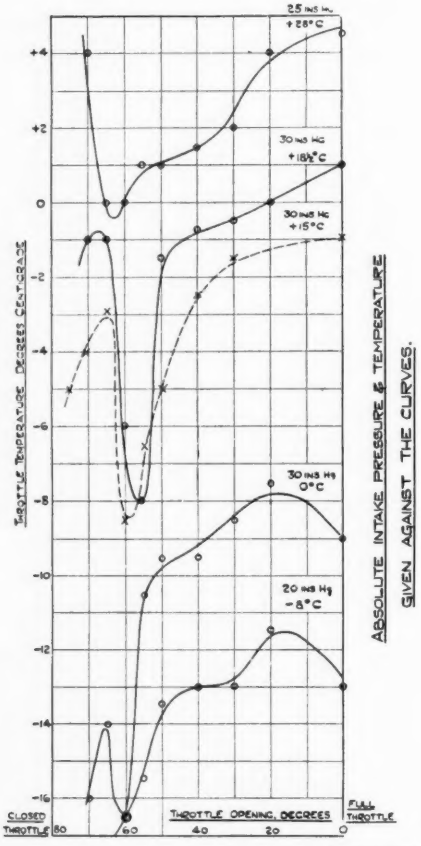

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FIG. 14.

For this particular carburettor the lowest throttle temperature would seem to occur when diving with the throttle about a quarter open (approximately one-third air flow). The variation of throttle temperatures with throttle angle for a number of intake temperatures and pressures is shown in Fig. 14. It will be seen that these curves agree with the conclusion that the coldest position for the throttle is about a quarter open. Changes in design will alter this position, but probably not very much.

Effect of Humidity

The influence of humidity has been considered already, but to verify the conclusions and to ascertain how far they would be modified by heat leakage, some measurements were made on the carburettor covering a range of humidities.

The measurements followed the general lines of the calculated temperatures, but were some two to three degrees centigrade higher. This may be explained by the effect of heat leakage and by the variation of the mixture from the optimum.

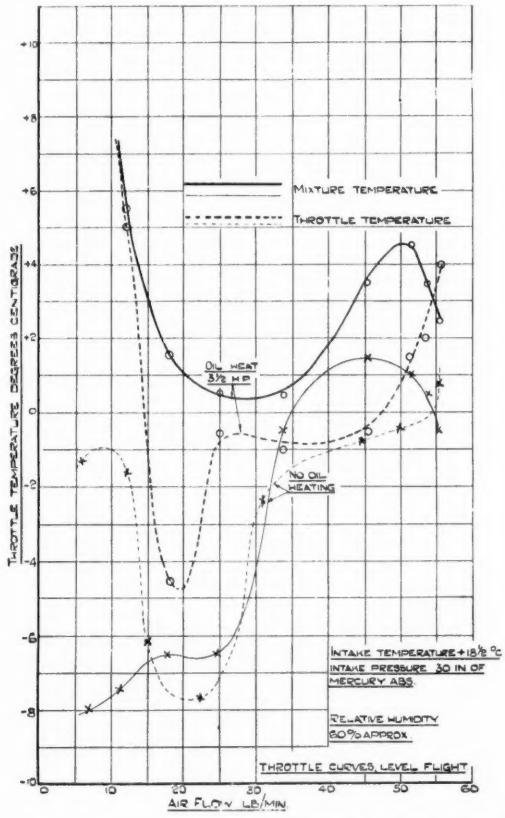

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FIG. 15.

Effect of oil heating on temperatures of mixture and throttle.

It will be shown later that an increase in humidity will result in an increased tendency to form ice provided the throttle temperature is below freezing, yet an increase in humidity tends to decrease the likelihood of that temperature falling below freezing. Humidity thus promotes freezing on the one hand and hinders it on the other.

Temperatures in a heated carburettor

The oil enters at the bottom of the carburettor just beneath the emulsion

tubes, passes round the jacketing of the chokes and the top of the carburettor and thence by a connecting pipe to the heater box jackets, the outlet being at the top of the heater box. During these tests the oil inlet temperature was usually between 80° and 90°C., the temperature drop across the carburettor and heater box jacket was about 7°C. and the oil flow about 25lb./min. This gives a rate of heat dissipation of about 3.8 h.p. The range of intake air temperature investigated was from $+18\frac{1}{2}$°C. to $-15\frac{1}{2}$°C.

With this rate of oil flow it was found that all parts of the carburettor were maintained above zero with the exception of the throttle butterfly. Apart from the throttle butterfly the lowest temperature recorded was +11°C. at the exit from the emulsion tube with an intake air temperature of −8°C.

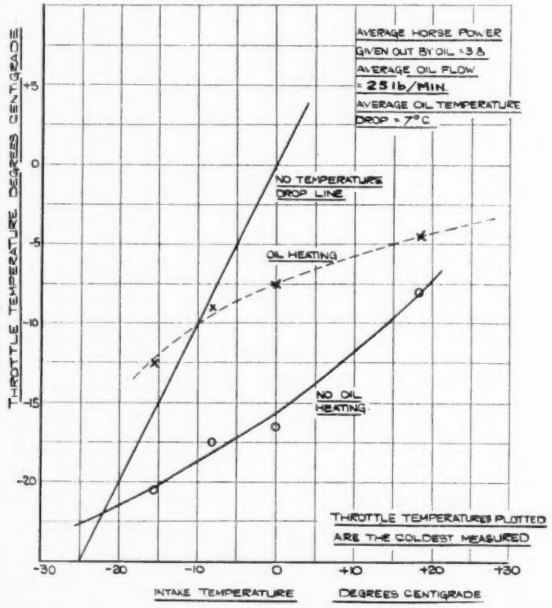

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FIG. 16.

Intake pressure 30in. mercury abs.
Relative humidity 60 per cent. approx.

The effect of the oil heating on the throttle temperature is shown in Fig. 15. The rise in temperature of the throttle is due to heat received partly by radiation from the walls surrounding it and partly by conduction along the spindle together with slight warming of the air as it passes through the lower part of the carburettor which is also jacketed. It will be seen that the heating is most effective at small throttle openings, presumably because the rate of heat abstraction by the mixture is less.

The corresponding change in mixture temperatures due to the oil heat is also shown in Fig. 15. In this particular test the heat supplied was sufficient to raise the mixture temperature above zero by the time it reached the exit of the heater box. At lower intake temperatures, however, the mixture temperature falls below zero even with heat supplied to the jackets. The effect of intake temperature

on the increase in throttle temperature due to the hot oil jacketing is shown in Fig. 16. The probable reason for the greater effect at the lower temperatures is that the same quantity of heat will raise the saturation temperature by a greater amount at the lower temperature. With no jacket heat, at $-20°C$. intake temperature, very little cooling due to the petrol evaporation occurs, and the oil heating increases this temperature to $-10°C$.

From Fig. 16 it is clear that the effect of oil jacketing is insufficient to raise the minimum temperature of the throttle above zero at any normal intake air temperature, and heat must therefore be applied directly to the throttle butterfly if ice formation is to be prevented. This has been done successfully in another carburettor, but no temperature measurements have been made and the matter will be referred to again when the question of ice accretion is considered.

PART III

ICE FORMATION

Test procedure

So far consideration has been given to steady conditions only, but when ice is forming in a carburettor the conditions are changing continuously and the time factor has to be taken into account. Tests were therefore made in the following manner. With no petrol flowing steady conditions of air flow, humidity, temperature and pressure were first obtained. Petrol was then turned on and observations made at frequent intervals of time, the time being measured from the moment of turning on the petrol. Intake conditions were as far as possible maintained steady during the test. When the test was concluded, the petrol was turned off, the ice allowed to melt away, the intake conditions altered and the procedure repeated. A preliminary survey indicated that, for this carburettor, 40° throttle was the most severe position and most of the work was carried out with this setting. This condition will, of course, vary to some extent with the design of the carburettor, and results obtained with this carburettor should not be applied to other types without due consideration.

Rate of ice formation

Some typical curves connecting air flow with time are shown in Fig. 17.

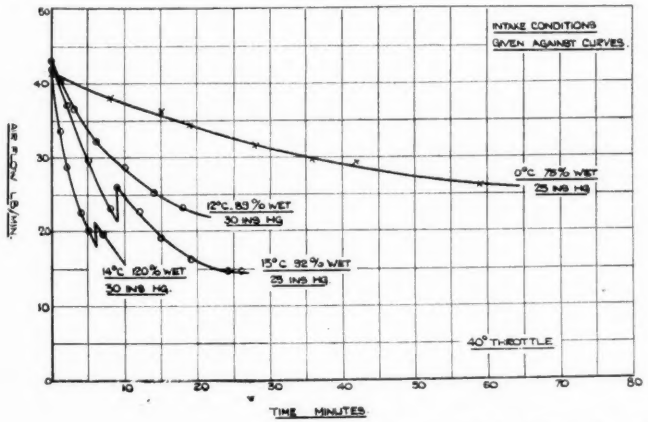

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FIG. 17.

The discontinuities that occur in two of these curves are due to small pieces of ice breaking away, presumably from the throttle. It will be seen that the curves tend to a minimum value of air flow which is in general not zero. There is thus a wastage of ice and the steady condition is reached when the wastage equals the rate of formation. There appears to be no simple method of comparing the curves obtained with the various intake conditions and it was finally decided to use the initial rate of decrease of air flow, and the final air flow attained as criteria of the severity of the freezing; of these the initial rate of decrease of air flow is probably the best as, unless ultimate failure is to occur, the freezing must not be allowed to proceed beyond the initial stages.

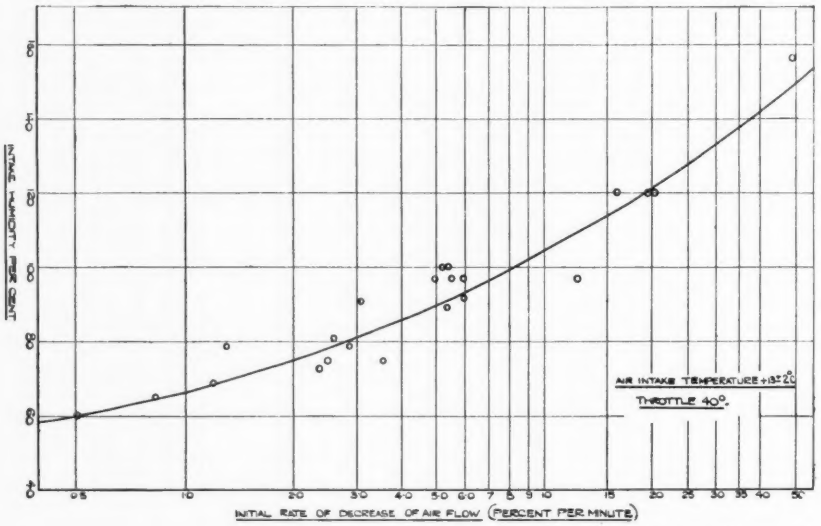
INTAKE HUMIDITY PER CENT
AIR INTAKE TEMPERATURE +13°C.
THROTTLE 40°.
INITIAL RATE OF DECREASE OF AIR FLOW (PERCENT PER MINUTE)

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FIG. 18.

Initial rate of freezing

Fig. 18 shows the variation with humidity of the initial rate of freezing as a percentage of the initial rate of air flow. For convenience the abscissa is shown with a logarithmic scale and the curve is for an intake temperature of $+13°C.$ $\pm 2°C.$ and a throttle setting of 40°. The intake pressure was sometimes 30-inch of mercury and sometimes 25-inch of mercury. The initial rate of decrease of air flow becomes very small at a relative humidity of 57 per cent.; this is the humidity at which the air is just saturated at the throttle pressure and temperature and therefore no ice formation would be expected. Of course this figure is only applicable to the fuel used in these tests, and fuel with a greater volatility would be expected to require a lower intake humidity for no ice to form.

As far as the experiments have gone, intake pressure does not appear to have any influence on the rate of freezing, although from theoretical considerations it might at first be thought that the lower the pressure the more severe the conditions for the same intake air temperature. Owing, however, to the increased influence of the water vapour as the pressure is reduced, it happens that, with constant intake humidity, the severity of the freezing is little affected by the pressure of the intake air. Fig. 19, which has been calculated by the

method referred to earlier, illustrates this; it shows the intake air temperature required so that the final temperature will just be 0°C. for a range of humidities and several intake pressures. In this case the pressure reduction actually decreases the severity slightly. The American experimenters[5] have also come to the same conclusion; they say in their report that fuel volatility is a much more important factor than altitude, *i.e.*, intake pressure.

The effect of intake air temperature is shown in Fig. 20, the throttle being at 40° as before. The initial rate of decrease of air flow is plotted against intake air temperature for several relative humidities of the intake air. The chain dotted lines are lines of constant water content and show the effect of heating the intake air on the severity of freezing. Although the number of points is rather

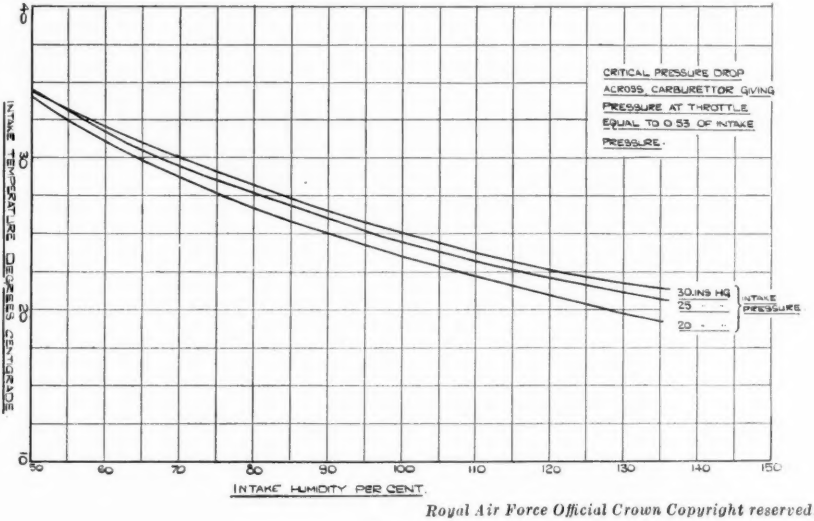

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FIG. 19.

small it appears that the rate of freezing is greatest with an intake air temperature of +13°C. The rate of freezing would be expected to increase with the temperature as the water content for the same humidity will also increase with the temperature. The upper limit will be set by the throttle temperature rising to 0°C. and this occurs for the throttle setting used with an intake air temperature of 22°C. and 100 per cent. humidity. Consequently the upper limit is about 20°C. The lower limit to the rate of freezing depends more on the humidity than does the upper limit, and it is not very definitely determined in the figure. That there should be a lower limit depends on the fact that, a certain degree of supersaturation appears necessary before appreciable quantities of ice are deposited. From the figure the limit for 100 per cent. relative humidity would seem to be between −10° and −20°C. Flight experience confirms these tests as it is found that cases of freezing occur most frequently when temperatures are near 0°C.

Final air flow

When a carburettor freezes, the air flow through it decreases with time approximately logarithmically until a final steady air flow is reached, which is in general greater than zero. By plotting the final air flow against relative

humidity for a number of tests in which the intake air temperature varied from $-5°C.$ to $+15°C.$ and the pressures were sometimes 30 and sometimes 25 inches of mercury, confirmation was obtained of the deduction from Fig. 18 that no freezing occurs with a relative humidity less than about 60 per cent.

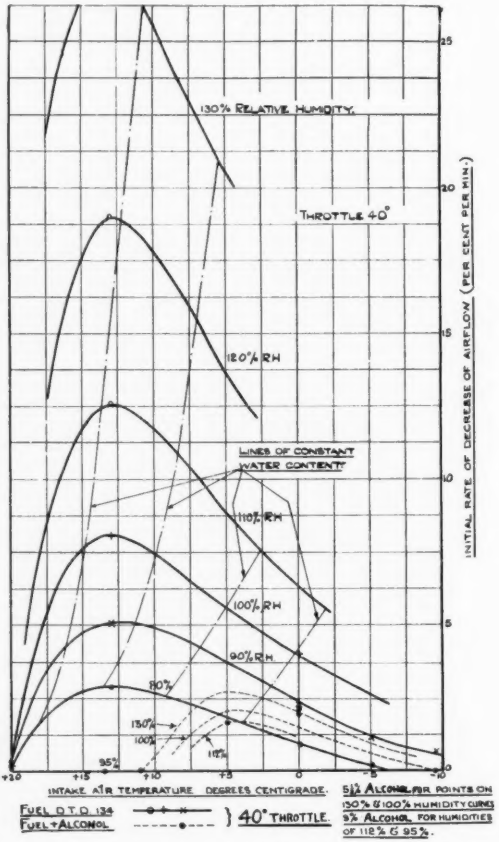

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FIG. 20.

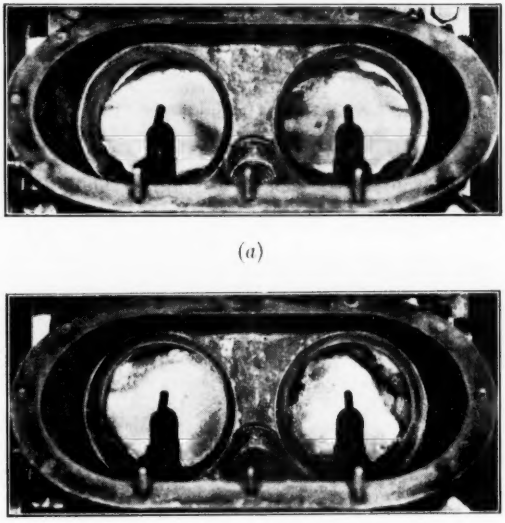
Effect of throttle opening

Sufficient tests have not been made to determine completely the effect of throttle opening on the tendency to freeze, but a number of general conclusions may be drawn from the information available. As the greatest temperature drop at the throttle occurs between 60° and 40° throttle angle it would be expected that the freezing tendency would be most pronounced in that region and this appears to be so for this carburettor. With high intake air temperatures it is only possible to freeze at part throttle, but as the temperature is lowered the throttle range over which freezing occurs will be increased and it is difficult in the absence of extended tests to say what region will be most severe.

Even when freezing is not possible at full throttle it is possible to arrive at the full throttle position with ice which commenced to form at a smaller throttle opening. As ice builds up, a pilot is liable to open up gradually in an effort to maintain engine power or speed, until he finally arrives at full throttle with cruising power, and an automatic boost control would behave in the same way.

Nature of the ice formation

The nature of the ice formation in the carburettor is shown in Fig. 21, which is reproduced from photographs. These photographs were obtained on another carburettor, but the ice formation illustrated is very similar to that obtained with the carburettor with which most of the tests were made. The top picture was taken three minutes after the start of the test, the intake air temperature being 15°C. and a water spray being used to increase the humidity to about 80 per cent. relative humidity. The lower picture shows the result after 12 minutes with the same conditions.



(*a*)

(*b*)

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FIG. 21.

Ice formations on throttle.

In Fig. 22 are several sketches of the ice formation obtained with the original carburettor under various conditions. The greater part of the ice accumulation is on the side of the throttle away from the engine and the lower the intake temperature the more the ice forms on this side. The observations have been confirmed by others made with a throttle mounted in a glass tube. It is remarkable how small a quantity of ice will cause a loss of power if the ice occurs in the right place and the ice seems to be deposited first in such a position as will cause loss of power. With the glass tube it was noticed that ice would build out from the sharp edge of the throttle across the air stream towards the wall and a corresponding deposit would form on the wall and build towards the throttle. Probably the extra depression caused by the sharp edge helps the ice formation.

The table below specifies the conditions under which the ice formation shown in Fig. 22 were obtained:—

Test No. (Fig. 22)	A	B	C	D
Throttle opening ...	40°	0°	40°	0°
Intake temp. °C. ...	+11	−1	+3	+8
Intake pressure (Ins. Hg. Abs.) ...	29.4	24.9	30.0	24.7
Intake humidity %...	97	120	85	120
Oil heating h.p. ...	None	None	$3\frac{1}{2}$	$3\frac{1}{2}$
Air flow (% of initial air flow)	37·3	23.8	17·3	—
Volume of ice on or near both butterflies (c.c.) ...	40	120	—	160
Remarks		Carburettor frozen at 40° and throttle then gradually opened to 0° and left for a few minutes.		Carburettor frozen at 40° and throttle then gradually opened to 0° and left for a few minutes.

The formation shown at B is of particular interest as it illustrates the accumulation of ice with progressive opening of the throttle. The ice formation shown would be obtained in well under ten minutes; moreover, the ice deposit would increase beyond that shown in the figure until the air flow was reduced to about 10 per cent. of its normal full throttle value. The engine would then be barely ticking over and a forced landing probably result. It will be noticed that in this test the slow running holes are blocked up; this is not usual, the tendency being for the ice to accumulate so as to allow the fuel to continue to flow.

Effect of jacket and throttle heating

C and D of Fig. 22 illustrate the influence of jacket heat on the ice formation. Although ample jacketing was provided on this carburettor the radiation from the walls was insufficient to prevent the formation of ice on the throttle butterfly, although the heat input was 3.8 h.p. This heat does, however, raise the throttle temperature some 3° to 9°C. and so necessitates lower intake temperature to cause freezing. In view of this, the possibility of heating the throttle butterfly by means of a stream of hot oil or other fluid passed through the throttle spindle was considered and carburettor manufacturers produced several designs of carburettors which incorporated oil-heated throttles.

In all the carburettors, which are illustrated in part in Figs. 23 to 26, the heating oil was passed through the spindle into a space cored out of the throttle butterfly. In one (Fig. 23) the circuit was in parallel with the oil jackets, in the others the jackets, when provided, were in series with the throttle passages, although in one (Fig. 24) oil heating was applied to the throttle only. The provision of adequate oil passages through the throttle has necessitated an increase in the throttle barrel diameter.

The method of test was as described earlier, the throttle position, humidity, and temperature being adjusted until freezing occurred. Ice accumulated in the carburettor illustrated in Fig. 23 with an intake temperature of 2°C., pressure 29 inches of mercury absolute, and relative humidity of 100 per cent., the throttle angle being 20° (shut throttle 70°). Examination of the carburettor revealed that the ice had formed over the throttle butterfly in the manner illustrated by C Fig. 22. As the hot oil was circulating through the carburettor at a rate of 23 lb./min., it was concluded that the throttle oil passages were too small and that the oil, cooled by the petrol evaporation, became so viscous that the pressure was not sufficient to force it through the throttle.

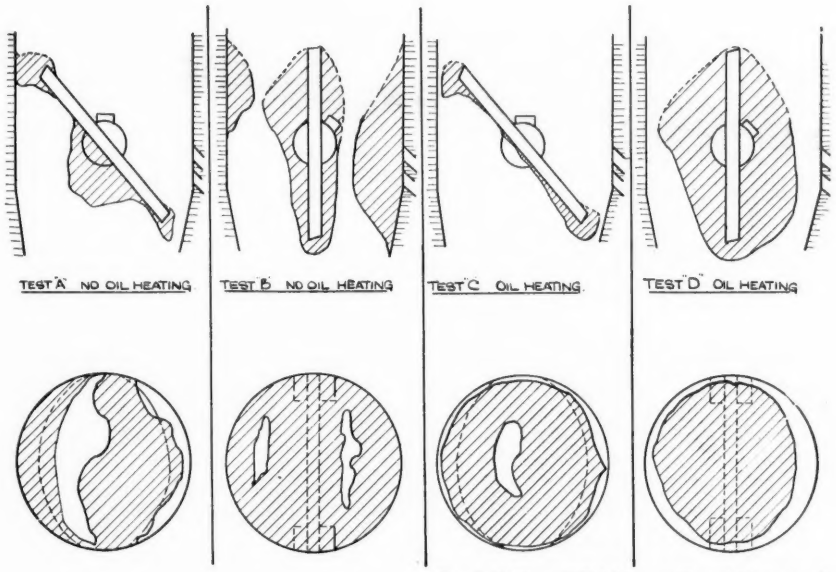

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FIG. 22.

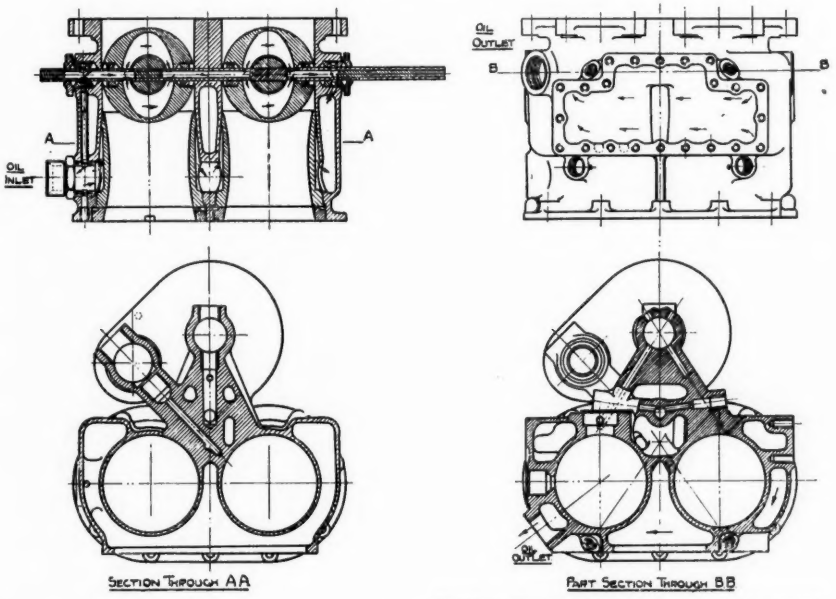

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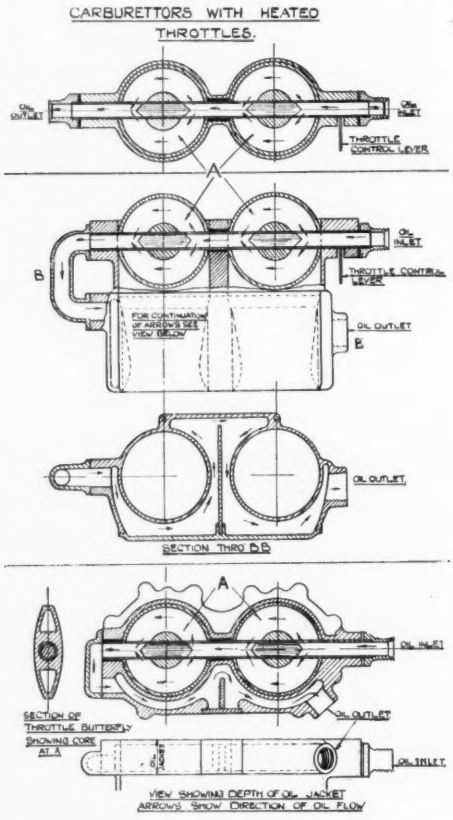
FIG. 23.

Carburettor with heated throttle.

With the design illustrated in Fig. 24, although the throttle remained quite clear of ice and the pressure difference required to force the oil through the throttle passages was small (12 lb.* per sq. inch for a flow of 25 lb./min.), ice built up on the walls of the throttle barrel, which were unheated, and partial blockage occurred. By closing the throttle the ice could be melted, but it would hardly be possible to adopt this expedient in flight. By slowly opening the throttle a considerable quantity of ice could be accumulated on the walls. This ice accretion could have been prevented by adequate oil jacketing wherever petrol-air mixture strikes the walls.



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FIGS. 24, 25 AND 26.

The next design (Fig. 25) was no better, as the jacket heat was applied round the chokes and not round the throttle barrel where it was required. Conduction of heat along the walls was not sufficient to prevent ice accumulating, and this version became blocked as rapidly as the previous one.

* When starting from cold the pressure rose to about 20lb. per sq. inch until the cold oil was displaced by hot.

In the last design tested (Fig. 26), oil heating was applied to the throttle and to one side of the throttle barrel. There are design difficulties in applying heat all round the barrel because of the presence of slow running jet passages. With an intake temperature of 3.5°C., pressure of 29 inches of mercury absolute, relative humidity 120 per cent. and throttle 40° (shut throttle 75°), a small quantity of ice accumulated at the opposite side of the throttle barrel to the oil jacket. It is probable that this carburettor, if fitted to an engine, would remain free from ice, as some additional heating would be obtained from the engine itself. It must be borne in mind, however, that prevention of freezing in the carburettor does not remove the possibility that ice may accumulate on the walls of the induction pipe above the carburettor, unless these also are heated. During the course of the above tests it was found necessary to supply heat at an elbow of the test plant above the carburettor to prevent the accumulation of ice there.

Heat Absorbed

Measurements of the heat absorbed from the oil, which are only approximate because of the small temperature differences, are tabulated below:—

Carburettor reference	Fig. 23.	Fig. 24.	Fig. 25.	Fig. 26.
Air flow, lb./min.	60	70	65	70
Fuel/air ratio % of correct (1 : 14.6)	140	118	112	110
Oil flow, lb./min.	23	25	25	25
Oil pressure difference across carburettor, lb./sq. inch	—	12	12	15
Oil temperature, °C.—				
Inlet	89.5	84	80	82
Outlet	86	82	78	80
Difference	3.5	2	2	2
Rate of heat exchange, assuming Sp. Ht. of oil 0.5—				
Centrigrade heat units per min.	40	25	25	25
Horse-power	1.7	1.0	1.0	1.0

It will be observed that the addition of the jacket to carburettor (Fig. 24) had no measurable effect on the heat transfer, probably because in Fig. 25 it was in an ineffective place, and in Fig. 26 it covered a relatively small area of the throttle barrel. With more efficient oil jacketing, such as that of Fig. 9, a further 3 h.p. could probably be transferred, giving a total of 4 h.p. With an air flow of 60lb./min. the latent heat of the petrol, if it were all absorbed from the jacket oil, would require a heat transfer rate of about 18 h.p. How much of this could be transferred in a carburettor and induction system is not evident, as part of the fuel must pass through the carburettor without touching the walls, although it probably reaches the walls of the induction pipe later if it remains in the liquid form.

If this source of cooling could be tapped it should form a useful oil cooler as the heat absorbing capacity would be proportional to the engine power. R. J. Penn has said[6]: "In designing a carburettor it might be considered as a heater box in which the essentials of a carburettor are fitted." If a non-freezing carburettor is to be developed using jacket heat, this should be borne in mind. Although difficult, it would not seem impossible to combine the jacketing of the carburettor, illustrated in Fig. 9, with the heated throttle of Fig. 26. It is essential, however, that the oil jacket and the throttle passage be in series and not in parallel.

Tests made with a carburettor attached to an engine

An investigation into the freezing of a Jupiter VIIF. engine in flight has

been made by the Bristol Aeroplane Company. It was not found possible to freeze the carburettor under the atmospheric conditions obtaining at the time of the tests, even with cold air intakes, and freezing was induced by spraying water into the intake air. To simplify the tests the added water was kept constant at 200 per cent. relative humidity calculated on the free air temperature. Under these conditions fading of the engine occurred (presumably due to freezing) with engine speeds near 1,300 r.p.m. (normal engine speed 1,775 r.p.m.) when the intake air temperature was between 16°C. and 2°C.; the freezing was most severe with intake temperatures near 9°C. A thermometer was inserted in the mixture stream at the elbow above the carburettor and when failure occurred the temperature recorded by this thermometer was between −2°C. and −14°C.

With a Mercury IV engine on the test bench, it was observed through specially inserted glass windows, that ice accumulated on the trailing edge of the throttle and at the elbow above the carburettor. By gradually opening the throttle to keep the speed constant as the ice built up, a considerable quantity of ice could be accumulated on the throttle.

Comparing these results with those obtained on a carburettor alone, it will be seen that the proximity of the engine narrows the intake air temperature range over which freezing occurs from +18°C. to −10°C. to +16°C. to +2°C. for this particular engine and carburettor.

PART IV

PREVENTION OF FREEZING

Jacket heat

It is clear from the tests that ice formation may be prevented entirely by adequate oil jacketing, embracing the throttle butterfly and all other parts of the carburettor and induction system on which ice is liable to accumulate. This is important as conduction along the walls cannot be relied upon to any great extent, because of the large capacity of the petrol mixture for heat absorption.

Water jacketing could be substituted for oil, but water is dangerous as it may freeze, as happened during the war in winter when tired lorry drivers allowed water to remain in their carburettor jackets over night and promptly froze it when starting in the morning, with consequent bursting of the jackets.

Intake heat

Intake heat has been used with varied success for the prevention of freezing. It has, however, the disadvantages that high intake temperatures are necessary to prevent ice formation on some days, and unless some form of control is provided this temperature has to be used always. If a heating control is provided then the pilot usually has to decide when freezing is liable to occur, and this is not always easy. Meteorological forecasts can only be general and some severe local condition may be encountered. According to the tests illustrated by Fig. 18 to prevent ice formation, the heating has to be such as will reduce the relative humidity below 60 per cent., say to 50 per cent. These figures apply only to the carburettor and fuel used in the tests, but there appears to be no reason why they should not be of more general application as regards carburettors.

With saturated intake air an increase in temperature of 12°C. will reduce the relative humidity to below 50 per cent. when the intake temperature is 15°C. or lower. These are not very large increases in intake temperature and reports of failures due to freezing have been received from aircraft with intake heating exceeding these values. It follows, therefore, that on bad days either the relative humidity is over 100 per cent. or the heating is not so great as was supposed. As the intake heating will probably have been measured on a dry day it will be

less effective on a wet one, because of the liquid water present. Earlier in this paper 130 per cent. relative humidity was considered to be the highest humidity which would normally be encountered and the condition will be most severe if part of the water is liquid. To reduce this humidity to 50 per cent. will require an increase in temperature of 25°C. measured on a dry day, although the actual increase in temperature required to reduce the relative humidity to 50 per cent. is only 17°C., the other 8° being required to evaporate the liquid water. The same increase would be sufficient for supersaturation of the atmosphere up to 300 per cent. relative humidity.

By the use of internal air intakes most of the liquid water may be excluded and the temperature rise necessary to prevent ice formation reduced. Excluding supersaturation, about which there is not yet sufficient data available, a temperature rise of 15°C. would seem ample to prevent dangerous ice formation. If supersaturation is to be provided for, this will have to be increased to about 25°. With internal intakes no difficulty is experienced in obtaining the required increase in the temperature of the air.

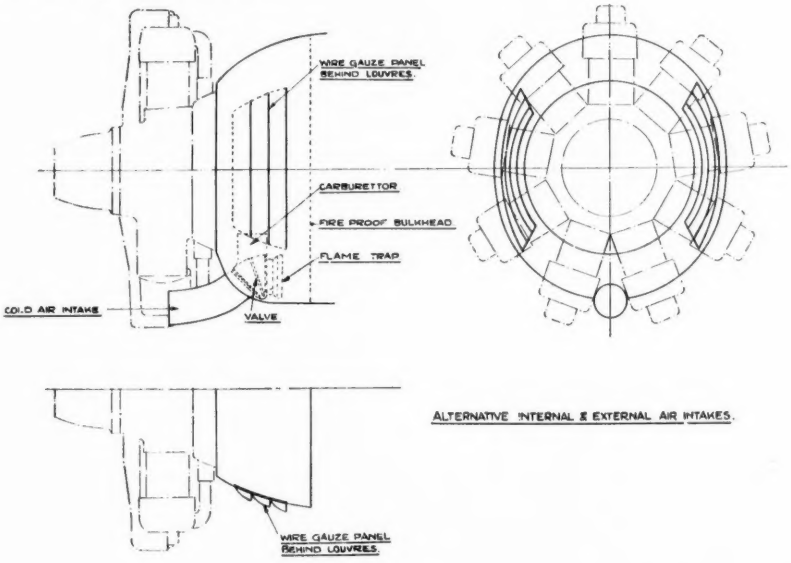

FIG. 27.

An alternative intake is fitted in some aeroplanes by means of which warm air from the engine bay or cool air from outside may be admitted, but the pilot usually has to decide when to change from one to the other, although in some installations the shutter is interconnected with the throttle. A diagrammatic illustration of such an installation is given in Fig. 27. If some form of ice detector could be installed in the induction system to give a warning when ice is accumulating, then the heat could be regulated automatically or manually to prevent the ice building up. Such a detector has been developed and will be considered later in this paper.

Ice inhibitors

An attractive method of preventing ice formation, suggested by A. A. Griffith,[7] is the use of some form of inhibitor which may be added to the fuel or

to the intake air and which will prevent the formation or building up of the ice. Such an inhibitor may be used continuously or added as required to break down ice which has already formed.

There are many substances which, when dissolved in water, lower its freezing point and cause such ice as may be formed to be soft and non-adherent. For engine purposes such a substance should preferably be a fuel and blend readily with aircraft fuels. This limits the choice to alcohols, such as methanol, ethanol or propanol. Of these methanol has most effect on the freezing temperature, ethanol is next, and propanol last, but they all have a marked effect, as can be judged from the following table:—

FREEZING TEMPERATURES OF WATER ALCOHOL MIXTURES.

Percentage of Alcohol in water.	Freezing Temperature C. (First Crystals). Methanol.	Ethanol.	Methanol 1 pint. Ethanol 1 pint.	Normal Propyl Alcohol	Iso Propyl Alcohol.
10	−6	−3·5	−4·5	−2	−2·5
20	−14	−7	−10	−4·5	−6
30	−24	−14	−18	−7	−11
40	Below −30	−22	−28	−9	−14
50	,,	−30	Below −30	−11	−19
70	,,	Below −30	,,	−14	−24
90	,,	,,	,,	−19	Below −30
100	,,	,,	,,	Below −30	,,

The ice that is formed when an alcohol water mixture is frozen undisturbed is a mass of interlaced needle-like crystals and therefore quite flexible. If it is stirred as it freezes it forms a pasty mass. Even a small proportion of alcohol in water (5 per cent.) is sufficient to affect the nature of the ice formation.

Methanol does not blend[8] readily with most fuels unless a blending agent is used, but the agent may be ethanol. Both ethanol and methanol separate from the fuel if a small quantity of water (less than 1 per cent.) is added to the mixture and thus will quickly combine with any water that may be present lowering its freezing temperature. Propanol does not separate completely from the fuel if water is added, but sufficiently so to hinder the ice formation.

Tests with Alcohol Added to the Fuel

Preliminary tests were made with the carburettor described earlier (Fig. 9) using fuel to specification D.T.D. 134 with various amounts of a 50:50 mixture of methanol and ethanol added, which mixture of alcohols blends readily with all fuels. As a limited supply of alcohol was available the greater part of the investigation was made on a much smaller scale, using a simple carburettor with a glass throttle barrel. The humidity of the air was controlled by adding water in the form of a fine spray, a sufficient length of pipe being provided to allow large drops to settle on the walls and be trapped before reaching the carburettor. It was not found possible to employ inlet temperatures below +2°C. combined with high humidities, on account of the rapid building up of ice on the walls of the choke, due to the evaporation of the water droplets in the air. (The cold air supply was unsaturated.) The most severe conditions for the carburettor appear, however, to be with an inlet temperature of +3° or +4°C. and the limitation is therefore not important.

Quantitative tests were made with the throttle two-thirds closed, as blocking was found to occur most rapidly when the throttle was in this position. The amount of blocking was assessed from the fall in the air flow rate and the increase in the depression across the throttle, the intake conditions being kept constant.

The procedure during a test was as follows:—After the temperatures, humidity and pressures had become steady at the required intake conditions fuel

was turned on and readings of the pressures made at timed intervals until the throttle was completely choked or for 30 minutes, whichever was the shorter time. Fuel was then turned off, the system thawed, and after conditions had become steady the procedure was repeated with a fresh fuel.

Because of the soft nature of the ice formed when alcohol fuel mixtures are used, measurements of the rate of blocking of the carburettor do not repeat very closely and the rate of building up of the ice is erratic. To differentiate therefore between the merits of different alcohols and different quantities of the same alcohol it was only possible to take a general survey of the results.

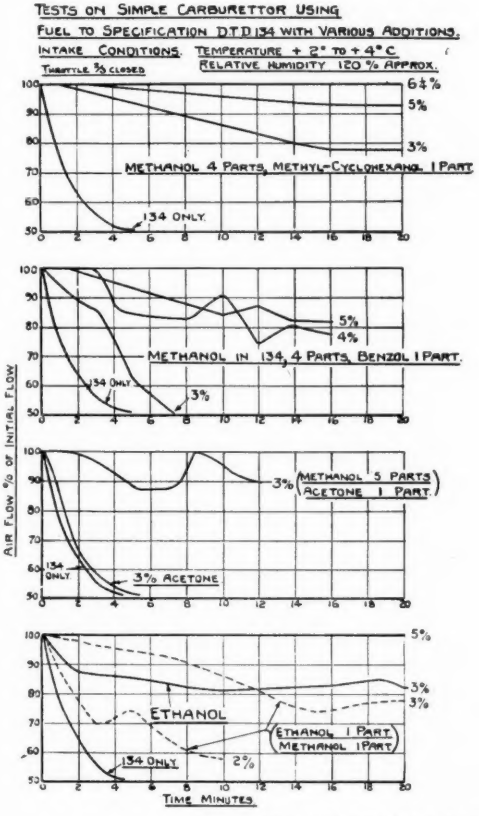

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FIG. 28.

The few tests made with the large carburettor are shown in Fig. 20, compared with the results of earlier tests. The reduction in ice formation with alcohol in the fuel is very marked. Insufficient observations were made to determine the shape of the curves when using alcohol and later tests on the simple carburettor, suggest that alcohol is even more effective than appears from these results. Typical examples of the tests made with the simple carburettor are given in Fig. 28. From a survey of the results it appears that 3 per cent. of any

of the alcohols used when added to the fuel effects a great reduction in the rate of freezing, and with the usual amount of intake and jacket heating this quantity would seem adequate to prevent blockage with ice under normal flying conditions. The addition of 5 per cent. almost completely prevents ice formation.

Some tests were also made in which the alcohol and fuel were introduced separately into the air stream, but the results were not sufficiently promising to warrant an extended investigation.

An automatic de-icing device

From these tests with alcohol additions it is clear that the use of fuel containing a small quantity of alcohol is a complete cure for carburettor freezing, although it will not deal with icing of the intake due to atmospheric conditions. Although the addition of alcohol to the fuel improves the anti-knock quality of the fuel there are objections to the continuous use of alcohol fuel mixtures. These objections are:—

1. *Blending.*—Alcohol does not readily blend with ordinary hydrocarbon fuels; ethanol will only do so when the water content of the alcohol is very low, and methanol requires the use of a blending agent.[8] The mixture cannot be stored over water and extreme care is necessary in eliminating water from fuel tanks to prevent separation occurring in the tank itself.
2. *Corrosion.*—The addition of alcohol to the fuel increases corrosion troubles, the mixture attacking most metals in varying degrees, particularly aluminium alloys unless they are suitably protected. The mixture is also a good solvent and attacks jointing materials and dopes.

It was not considered desirable, therefore, to use alcohol continuously in the fuel to prevent an occasional freeze and consideration was given to the development of a device which would add alcohol to the fuel only when ice was forming and at a point as close to the exit of the fuel from the carburettor as possible. Thus the importance of good blending properties is lessened and corrosion is less likely to occur because the system will be flushed with alcohol-free fuel when the engine is ticking over just before it is shut down. The device which was successfully developed originated with A. Swan and W. Helmore,[9] and comprises two essentials, the ice detector and the servo-mechanism which controls the supply of alcohol. The ice detector consists of two orifices arranged in the induction pipe in such a way that one orifice is adapted to be more rapidly obstructed by ice than is the other orifice. By allowing a small quantity of air to flow through each orifice and measuring the relative rates of flow by other orifices it is possible to observe, as a change in pressure difference, any change in the area of the detector orifice. This pressure difference is used to actuate the servo-mechanism, which obtains its motive power from the suction in the induction system.

Position and Form of Ice Detector

If the detector is to be sensitive to the onset of freezing, it must be exposed to the mixture stream at all throttle positions. The exact location is probably not important so long as warning is given before sufficient ice has accumulated to cause trouble. A position just above the carburettor and in line with the slow running jet exit is indicated, and observations made with a glass tube fitted above the carburettor showed that, if ice formed at all, there was always some ice on the wall in this position. Subsequent tests confirmed that this position gives a reliable indication.

After trials of a number of forms, the detector illustrated in Fig. 29 at *a* was found to be the best. It consists of two unequal apertures exposed to and facing the mixture stream so as to experience, as far as possible, the same pitot

pressure under all conditions of mixture flow. The proximity of the throttle makes this difficult, but the arrangement shown at *a* was found to give pressures, measured at the ends of the two pipes, that balanced within ± 0.2 inch of mercury. Form *b* was not so good, and *c* was definitely out of balance by about 1.6 inches of mercury, excess pressure on the larger orifice, at some throttle positions.

The arrangement shown at *d* could be balanced or thrown out of balance by rotating it about its longitudinal axis, and the bias thus given was maintained fairly closely over the throttle range.

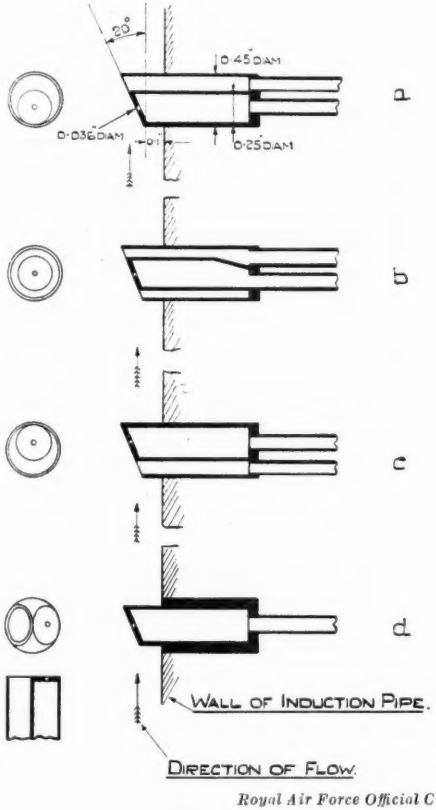

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FIG. 29.
Ice detectors.

Any ice building up on the face of these detectors will obstruct the small orifices more rapidly than the large ones, and so give an indication that ice is forming, by means that will be described later. It was found experimentally that, if an orifice is to be obstructed by ice building up on the face, the orifice must be exposed so that the particles of ice impinge on the edge of the aperture. This is satisfied by inclining the face to the direction of the mixture stream as shown in Fig. 29. Angles between 20° and 50° were found to be satisfactory. Outside this range the action was uncertain, and with 0° or 90° the aperture sometimes remained unobstructed.

The precise diameter of the smaller aperture of the detector was not found to be important, diameters from 0.03in. to 0.06in. being used successfully and giving an early indication.

Servo-Mechanism

The servo-mechanism is shown diagrammatically in Fig. 30. Air is admitted through two small and equal orifices *e* to the detector orifices, and thence to the induction pipe. The orifice *f* is of the same area as the smaller orifice of the detector, and, whatever the suction applied to the detector, while the detector orifices remain unobstructed there is no pressure difference across the diaphragm *g*, except for the small unbalanced pitot head previously referred to. When ice

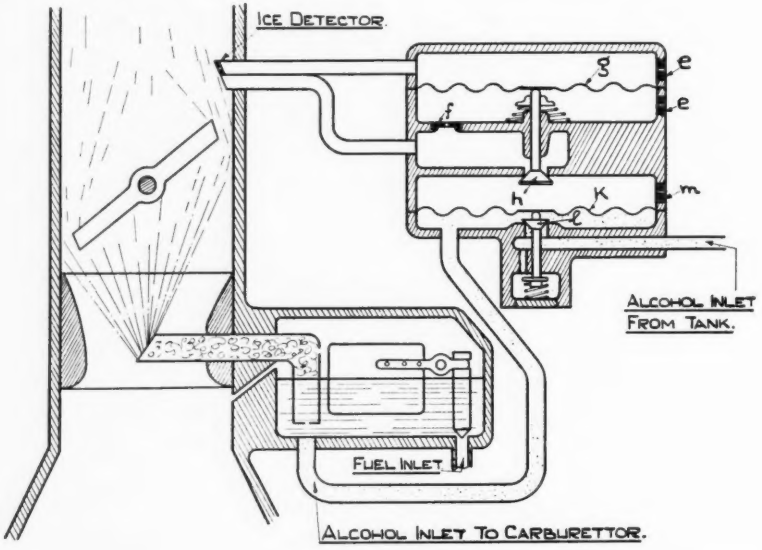

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FIG. 30.

Diagram of de-icing device.

begins to build up, the smaller aperture is first obstructed and the pressure above the diaphragm *g* rises and causes valve *h* to be opened. This allows the suction of the induction system to act on the diaphragm *k* and thus open the alcohol valve *l*, allowing alcohol to flow into the carburettor float chamber. The ice formed is cleared away by the alcohol and pressure balance restored across diaphragm *g*, and the valve *h* closes. Then through the air bleed *m* the pressure above the diaphragm *k* rises and the alcohol is shut off until such time as ice builds up again and the cycle is repeated.

The latest design of the unit is shown in Fig. 31. The unit weighs 1.5lb., and, with detector pipe work and bracket required to fit it to an engine but excluding alcohol and tank, the weight becomes 2.5lb.

In an early design an attempt was made to meter the alcohol, experience showed, however, that the mechanism never remained in action long enough to settle to steady conditions and the metering was not effective. The latest design, therefore, only includes a jet to limit the maximum flow of alcohol to

about 5 per cent. of the full throttle fuel flow. The unit shown in Fig. 31 requires the jet area to be adjusted to suit the head of alcohol. A somewhat heavier design (unit weight 2.5lb.), not shown, has an alcohol pressure control incorporated and the jet size can be fixed independently of the tank position.

When installing the unit shown in Fig. 31, care must be taken that the alcohol outlet from the unit to the carburettor is large enough to prevent pressure being developed in the unit sufficient to hold the alcohol valve permanently open.

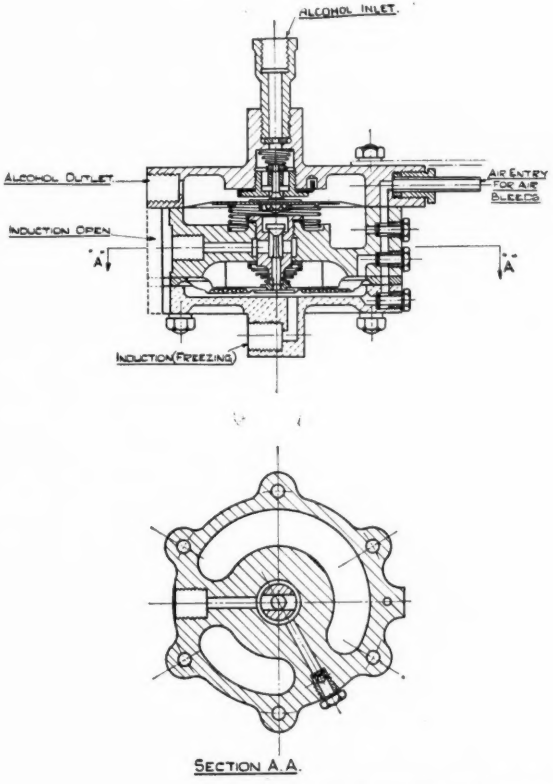

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FIG. 31.
De-icing device.

Tests of Unit

Preliminary tests of the unit were made by applying a pressure difference across the controlling diaphragm (*g* Fig. 30) and suction to the large detector orifice. No difficulty was experienced in assembling the unit so that a pressure difference of 0.3 inch of mercury would turn the alcohol full on with an applied suction of from 1 to 20 inches of mercury. For use the unit was adjusted so as to supply alcohol when the pressure difference and applied suction both exceeded 1 inch of mercury. It has been thought that differential adjustment of the air

bleeds *e* would be required to give satisfactory action, but this was found to be unnecessary. The air bleed orifices used are 0.01 inch diameter and the freezing detector orifice is 0.036 inch diameter.

After the unit had been tuned, it was tested on a carburettor under freezing conditions. A number of tests were made and the unit was found to keep the carburettor free of ice with an expenditure of alcohol of from 2 to 3 per cent. of the fuel flow, the exact figure depending upon the intake temperature and humidity and the alcohol jet size. By reducing the jet, smaller figures could be obtained. No attempt was made to obtain the minimum figure, as this will be better determined on engine tests. With an intake temperature of 15°C., 40° throttle angle (shut throttle 70°), and a water spray, giving a total relative humidity of about 80 per cent., the carburettor fuel flow was reduced initially by 3 per cent. per min., and quantities of ice built up on the throttle and on the induction pipe walls. Fig. 21 *a* and *b* show the conditions of the throttle after 3 mins. and 12 mins. respectively. When the de-icing unit was allowed to act it cleared away this ice in 15 secs. and kept the carburettor and induction pipe free from ice for 30 mins., when the test was discontinued. The expenditure of alcohol was 3.7 per cent. of the fuel flow when an alcohol jet supplying 11 per cent., if used continuously, was used; this was reduced to 1.4 per cent. when a jet supplying 5 per cent. was used.

For continuous freezing in flight, a quantity of alcohol approximately 2 to 3 per cent. of the fuel flow will be required, but as the incidence of continuous freezing is unlikely, the actual amount of alcohol to be carried should be much less and can be only determined from actual flight tests. The earlier tests with alcohol-fuel mixtures showed that a consumption of 3 to 5 per cent. of alcohol was required to prevent ice formation. From the tests with the unit it would appear more economical to use alcohol intermittently rather than continuously, probably because while the ice is re-forming no alcohol is used and also because the ice is partly detached by the action of the air stream once the sudden application of the alcohol has caused the ice to crack.

Reliability tests were made with the unit attached to a carburettor and subjected to a head of alcohol as it would be in an aircraft. During a period of two weeks the carburettor and unit were tested under freezing conditions at intervals, and the unit was found to respond to the detector and keep the carburettor clear of ice on every occasion. It is estimated that the unit operated at least 1,000 times during this period.

Quality of Alcohol to be Used

From the earlier tests it was concluded that ethanol and methanol were equally satisfactory as ice inhibitors. The tests of the unit were made almost entirely with ethanol, though methanol has been tried and found to be satisfactory. As alcohol is very hygroscopic, it was thought that a tank of alcohol might absorb water and cease to be miscible with fuel. Some tests were therefore made using wet alcohol that would not blend with the fuel. Industrial alcohol was first used; this contains 5 per cent. of water, and was found to be effective. Actually no difference could be detected between its action and that of the drier alcohol (3 per cent. water), although industrial alcohol would not blend with the fuel. Further dilutions were then tried, and even 50 per cent. alcohol-water mixture was found effective. Dry methanol was then tried and also found satisfactory.

It is not suggested, however, that alcohol which will not blend should be normally used, as it may increase the corrosion troubles, because it will be liable to lodge in pockets in the carburettor and may remain there when the engine is standing.

PART V

GENERAL CONCLUSIONS

In an unheated carburettor dangerous ice formation is likely to occur on days of high humidity with intake air temperatures between +18°C. and −10°C., and conditions will be most severe with temperatures about 13°C. Any heat gained by the carburettor or intake air will reduce the range over which freezing is likely and lower the temperature for the most severe conditions. Thus in partially heated carburettors the most severe conditions will occur with temperatures near 0°C.

There appear to be three solutions which, separately, if correctly applied, would give freedom from ice accretion in carburettors and induction systems, although certain difficulties have to be overcome whatever method is adopted. Considerations of other aspects of engine functioning may require heat, either as jacket or intake heat, to be supplied, and it is possible that the final solution in any particular engine may take the form of a compromise between or a combination of any of the methods enumerated.

The methods are:—

1. The use of alcohol.
2. Jacket heat.
3. Intake heat.

1. *The use of alcohol*

The use of alcohol will prevent freezing in carburettors; there is no loss of power due to additional intake heat and no necessity for awkward heating jackets and passages. If added to the fuel in bulk, special precautions are necessary to prevent separation of the alcohol from the fuel and the mixture is liable to cause corrosion and to attack jointing materials and dopes. If added as required to prevent ice formation as by means of the de-icing device described, these difficulties are avoided and more economical use of the alcohol is obtained. This method, however, requires the addition of this device and a small separate tank to the engine installation.

2. *Jacket heat*

With a carburettor and induction system designed for the purpose, jacket heat will prevent freezing. The carburettor will require an adequate heat supply to the throttle and walls wherever the mixture will cause cooling and this heating may have to be extended to the blower inlet vanes and casing in a supercharger engine. There is likely to be little loss of power due to the heat given to the air and there is a possibility of the carburettor being used as an oil cooler.

3. *Intake heat*

A temperature rise of 15°C. if liquid water is excluded should be sufficient to prevent freezing except with supersaturated air; to cover this the temperature rise may need to be increased to 25°C. The exclusion of liquid water could be achieved by the use of an internal or other suitably protected air intake. Loss of engine power due to heating the air may be overcome by providing an additional cold air intake for full throttle use. This system does not require any alteration to the existing carburettors and induction systems, and, with internal intakes, the balance of the carburettor should be improved.

Acknowledgments

In conclusion, I would like to express my thanks to those of my colleagues at Farnborough who have helped in the course of these investigations, and particularly to Mr. H. Constant, who assisted considerably in the earlier part of the work.

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Discussion

The Chairman: The applause following the presentation of the paper indicated that the meeting had fully appreciated the manner in which Mr. Clothier had dealt with the very difficult piece of research work which had been remitted to him and his associates. He had given an account of the theory by which they had proceeded and the conclusions at which they had arrived; and he had claimed, quite reasonably, to have put forward schemes which would overcome the difficulty of ice formation in carburettors. It would be interesting, therefore, to hear the opinions of other experts; and he invited Mr. Fedden to speak.

Mr. A. H. R. Fedden (Bristol Aeroplane Co., Ltd., *Fellow*): During the last few months the Bristol Aeroplane Co. had been carrying out quite extensive experiments for the Air Ministry, in which, by introducing suitable high humidity conditions, they had produced extraordinary quantities of ice in carburettors. The rapidity with which ice formed immediately the degree of humidity was raised was really surprising. If Mr. Clothier's de-icing scheme would solve the problem, it represented a very excellent and neat arrangement. The Bristol Co. were trying it at the present time, but the work had not yet proceeded far enough to enable them to form a definite opinion about it. They were intensely interested in it, and if it proved to be a satisfactory solution it would be certainly a very much neater and lighter arrangement than oil jackets or intake heating. As the result of a fairly bitter experience, Mr. Fedden was definitely of opinion that no oil jacket would deal with extreme freezing conditions, and he believed that exhaust heating would be the only solution. He believed that on the American air lines the demand was for a temperature rise of the order of 50°C.; that wanted a lot of doing, and he did not believe there was any other way than by exhaust heating. But with exhaust heating, where really considerable amounts of heat had to be dealt with, there was the problem of preventing the pipes interfering with the engine mounting, and it was for the aircraft constructors and those concerned with the engine installation to consider whether the pipes could be so arranged that they would not interfere with other parts of the aircraft.

The part of the paper which intrigued him most of all was that relating to the use of alcohol in the fuel, for de-icing; and he suggested that once they had broken through the objections to carrying a second fuel, if the authorities would allow a one-gallon tank to carry it, and the difficulties arising from the corrosive

properties of alcohol were overcome, they might as well have a larger tank and use alcohol also to add to the take-off power of the engines. The problem thus became doubly interesting, and he hoped sincerely that Mr. Clothier's de-icing device would prove a solution of the problem of ice formation.

Captain DODSON: He hoped he would be forgiven for the heresy of pointing out that oil or exhaust were not the only means of heating. It was possible to use a non-greasy fluid and evaporate it in the exhaust system. If one used water treated with alcohol, so that it would not freeze, the high latent heat of the steam would require an extremely small pipe to confine it, and there would not be fire risks caused by very high temperatures of the pipes.

Mr. H. CONSTANT (*Associate Fellow*): He confessed that the chief impression that the paper had left upon his mind was one of surprise and amazement that aircraft were able to fly at all. The author had pointed out that serious deposition of ice might occur on the throttle butterflies, over a very wide range of air temperatures and over a wide range of throttle openings, and under conditions of humidity which occurred very frequently in practice. Yet there did not appear to be a very great deal of trouble due to freezing in actual flight. Now and again a pilot had to make a forced landing, which was attributed to freezing because they could not think of any more reasonable explanation. But they did not have aeroplanes crashing from the skies every day, as one would expect after considering the curves and figures in the paper. It seemed that there was a discrepancy somewhere, and it was rather important to clear up that discrepancy. Why was it that aeroplanes could fly in all these various atmospheric conditions and yet very rarely suffer from carburettor freezing? Judging from the curves in the paper, one would expect that freezing would occur very much more frequently.

This led Mr. Constant to ask whether, if carburettor freezing were a fairly rare phenomenon in practice, it was reasonable to penalise aircraft performance by loading the aircraft with gadgets designed to cope with conditions which might arise perhaps only once a year. It was required to dissipate a certain amount of the heat in the oil, and that was done by sticking out a pipe into the air stream, so inducing drag. At the same time, there was a point in the carburettor system that they wished to heat. Surely the obvious thing to do was to overcome the mechanical difficulties and put the heat where it was wanted, rather than to carry an extra fuel tank and a rather delicate piece of mechanism which might go wrong at the critical moment.

Captain A. SWAN (*Associate Fellow*): So far as he was aware, Mr. Clothier's paper was the first which contained comprehensive data on ice formation and its prevention, and it should be extremely valuable to designers; they should be able to predict their designs with rather more accuracy in the future to obviate the difficulty.

Whilst it was true that freezing in carburettors was not very prevalent among aircraft in this country, its effect could be disastrous when it did occur. He was rather in agreement with Mr. Constant that there appeared to be a discrepancy as between actual flight conditions and the conditions under which bench tests were made. Possibly in actual practice the condition of high humidity was not frequent in this country; but in the United States, freezing of carburettors was a very serious matter, and he could only speculate as to the reason for that. The atmospheric conditions which promoted freezing might occur more often there than here; perhaps the machines in America were flown in weather conditions that were worse than we considered suitable for flying; possibly the fuel they used had greater volatility and promoted evaporation and freezing more quickly than our fuel; or possibly the carburettors they used atomised the fuel more than ours and so gave more encouragement to evaporation and freezing. But the problem was so serious there that it had in large measure caused the

Americans to give serious attention to the direct-injection engine, thus eliminating the carburettor altogether and avoiding the possibility of carburettor freezing.

The engine constructor would be concerned mostly with the prevention of freezing, and if he could do that in a simple manner, without adding greatly to the weight of the engine, he would probably do it, even to avoid only occasional liability to freezing, with the possibility of a forced landing. The method adopted by a constructor would probably depend upon his particular engine. Some engines did not like heated air, whereas other did; in some engines heat could be added without complicating the installation, whereas in others it would be very difficult to arrange for the added heat. Captain Swan looked forward with extreme interest to the solutions finally adopted in the various types of aircraft engines used in this country.

Mr. E. L. Bass (*Associate Fellow*): With reference to the fuel characteristics which were said to control freezing in carburettors, he asked if Mr. Clothier could explain why the experiments had shown these to be related to the 10, 20 or 25 per cent. temperatures, and not to the dew point. One would have thought, from first principles, that the dew point would have been the determining characteristic; he believed the Americans had found that carburettor freezing was dependent upon the 50 per cent. temperature, which was more in line with the dew point than the boiling range temperatures as found in the R.A.E. experiments.

A Speaker: He supported Mr. Clothier's view concerning the importance of preventing ice formation in carburettors, as against the argument that forced landings due to that cause were not frequent in this country. He said that in the course of one day's operations by three or four machines there were 18 forced landings, and he personally had had a part in five; and over the rest of the week there was an average of seven forced landings by four pilots. Such forced landings occurred as a rule under conditions of some danger, such as when fog or snow prevailed, so that the risk of anything in the nature of a crash was a fairly serious one.

He also asked if there were a potential relationship between the icing up of the whole aeroplane and the icing of the carburettor—whether the formation of ice in the carburettor could be regarded as a sort of empirical test of the inevitability or otherwise of ice formation on the aeroplane as a whole.

Mr. Constant: Had the speaker any particular reasons for suspecting that the forced landings to which he had referred were due to carburettor freezing, or whether they might have been due to some other cause?

The Speaker: The whole of the evidence pointed to icing of the carburettors as being the cause. The first symptom in each case was a slight reduction of revs., accompanied by a strong mixture, as indicated by a sooty exhaust. After flying for about five minutes after those symptoms had developed, at full throttle, the effect of the exhaust was something approximating to sky-writing. The condition was slightly improved afterwards by opening the altitude control, which had the effect of closing the throttle. Those two symptoms together provided almost conclusive evidence.

Mr. E. I. M. Emtage: A feature of trouble due to freezing was that it was epidemic. He recalled that some years ago very serious epidemics of failures had occurred in a certain type of training machine, and were pursued from Lincolnshire to all parts of this country, and even to Northern Ireland. There were intervals of weeks between these epidemics. A carburettor which had given this trouble was taken to Farnborough and subjected to tests similar to, but much more primitive than, those described in the paper, and it was only then that those concerned had really got down to the problem. One of the symptoms was a very gradual, and finally acute, enrichment of the mixture as the ice built

up around the throttle, opposite the slow-running jet outlet and thereby increased the velocity of the air past the outlet. It was found that by opening the altitude control one could clear it temporarily; sometimes the trouble was cured completely in that way.

On the occasion of the opening of the Northern Ireland Parliament a detachment of three machines had had to fly to Belfast, and when crossing the mountains in Antrim, all three of them had experienced freezing trouble; when over Belfast the three pilots had found that the fuel mixtures were becoming gradually richer, and that black smoke was issuing from the exhausts. Two of them were able to carry on by opening the throttles, but the third had had to make a forced landing.

It would appear that the discrepancy between the infrequency with which these cut-outs occurred in practice and the regularity with which they could be produced in the laboratory was due to the very rapid variations of conditions during flying. One typical failure which still occurred from time to time was one in which an aircraft would have its engine ticking over for some time, would then taxi and take off, climb 200 or 300ft. and then cut-out. Presumably ice was building up during the whole of the time the engine was ticking over. It was quite possible that if the machine reached safely a height greater than 200 or 300ft. the change of attitude or the change of throttle opening might raise the temperature, or the ice might become mechanically broken away. The fact that the conditions might vary almost from moment to moment in the air might ensure very often that when ice did begin to form it was cleared immediately.

Mr. Emtage associated himself with the opinion expressed by Mr. Fedden concerning oil heating, and said he considered it was a broken reed. It was very good in the laboratory and on the test bench, but in the air it might let one down. As to the use of alcohol, he recalled that years ago he had devised a carburettor which would use both alcohol and petrol as and when they were needed; but the difficulty of carrying two fuels in the Service or in civil aviation was too great. Even the carrying of the small quantities of alcohol which would be required for the specific purpose of de-icing carburettors might be considered to involve too much complication under normal operating conditions. Possibly the best and most practical solution of the icing problem was the internal air intake, with a proper flame-damping device. Such an intake would help to draw cold air over the various auxiliaries, such as generators and air compressors, which perhaps suffered from heat at present; and it would help to exclude snow or even sand from the engine.

Captain W. J. STERN: Apparently freezing was due largely to the spray action of the fuel upon the throttle. Why was it necessary to place the throttle in such a vulnerable position? He suggested that if it were placed higher, or preferably, if there were suitable bends in the carburettor system, it would be easy to arrange that the spray would not impinge on the throttle; thus, heating would become very much easier.

Mr. P. NARRIS: Have experiments been made to heat carburettors electrically, for that seemed to be the simplest and probably the most economical method?

Mr. H. B. TAYLOR (*Associate Fellow*): He suggested that possibly a reason why the practical and laboratory results could not be correlated, even though the rate of ice formation might be the same in both circumstances, was that when an aeroplane was in flight the ice formed would frequently break off and pass through the engine. During the type test of a certain engine in extremely humid weather, pieces of ice could be picked up from the floor, having passed right through the exhaust valves. The breaking up of the ice as it formed, when a machine was in flight, was probably assisted by the vibration of the

engine; and that breaking up might be the reason why forced landings were not so frequent as might be expected.

In the case mentioned by another speaker where numerous forced landings were made during the course of a day, due to ice formation, it is probable that the engine induction system had no form of heating whatever, which would account for the frequency of the trouble.

The CHAIRMAN: The investigation of ice formation in carburettors was rendered particularly difficult because one could not actually see, when in flight, whether it was happening; one had to proceed so often by inference; whereas ice formation on other parts of aircraft could be seen easily, and there were various methods, of a more straightforward character, for dealing with it. The solutions put forward by the staff at Farnborough were interesting examples of the use of the research method, for the staff had endeavoured to show, not merely how the ice, when it formed on carburettors, could be disposed of, but also how the very formation of the ice could be inhibited. It was for those concerned with the investigation of remedial measures to suggest what they considered to be the most feasible means of achieving the desired end, and this Mr. Clothier had done; and it remained for the user to decide which of those alternatives he preferred to use in practice.

Mr. A. F. ELLIOTT (Bristol Aeroplane Company) (*communicated*): There is one aspect of this problem which did not occur to the speaker at the time the paper was discussed, viz., the possibility of carburettor freezing when gliding through cloud or atmospheric conditions which might promote freezing.

The freezing tests that the Bristol Aeroplane Company carried out under flight conditions were undertaken as a result of reported carburettor freezing in about six cases during night flying, and whilst machines were cruising round the aerodrome awaiting the signal to land. This really set them a new problem because, although the heat efficiency of their air intake was such that they obtained a rise of 35°C. at the higher throttle openings, they found by further experiments that this figure was reduced to 10°C. when gliding down for approximately 2,000ft. This experience emphasises the fact that practically no heat is being dissipated by the engine whilst gliding with a small throttle opening and therefore freezing may well occur. To obviate failure under these conditions, it would be necessary to adopt either one of the following arrangements:—

1. To adopt some form of heat collector which would store sufficient heat to be expended during gliding.
2. To instal some auxiliary form of heating which would be entirely independent of the engine.
3. To employ some other de-icing apparatus entirely.

They attempted to apply a scheme based on (1), but this did not develop successfully and was quickly abandoned. Any form of auxiliary heating as required by (2) above would be automatically ruled out on a question of weight. This left them with the third proposal, and it appears to the writer that the alcohol de-icing scheme as proposed in the paper is the only promising solution known at the present time.

REPLY TO DISCUSSION

He agreed with Mr. Constant that it appeared at times that freezing was a convenient excuse for an unexplained trouble, but there is evidence (such as that given by Mr. Fedden and another speaker) that ice formation does occur in flight. Pilots had reported, for instance, that their engine throttles had jammed and that they had been unable to free them until they had descended to lower altitudes. One pilot reported after a forced landing that there was water coming

out of his air intake, and it was stated recently in America* that, " Investigation of air line accidents and forced landings by the Bureau of Air Commerce have revealed that carburettor icing is still the major cause of aircraft engine trouble. During 1934 passenger-carrying aeroplanes were forced down in 26 cases because of ice formation in the carburettors."

It was true, as Mr. Fedden said, that oil jacketing alone could not prevent ice formation, but with due deference to Mr. Fedden's experience Mr. Clothier would suggest that adequate oil jacketing combined with effective throttle heating would solve the problem. With efficient oil jacketing the large quantity of heat absorbed in the carburettor would considerably reduce the size of the external oil cooler required.

If intake heating by means of exhausts was used—and Mr. Fedden was of the opinion that only in this way could adequate heat be provided—50° rise in temperature should not be necessary if precautions were taken to exclude rain or snow from the intake air.

The use of alcohol certainly has the advantage of simplicity, and if the difficulties of storage and corrosion could be overcome an alcohol fuel mixture would eliminate the need for gadgets, but a gadget was preferable to the possibility of the fuel separating out during flight.

Mr. Clothier agreed with Mr. Swan that it will be extremely interesting to see which method is finally adopted by the various manufacturers.

In reply to Mr. Bass, he stated that the measurements made with the R.A.E. spray apparatus are not directly comparable with the American measurements. The former apparatus measures the lowest temperature attainable with water-free air, whereas the American measurements were limited to a definite air-fuel ratio, and as far as can be determined from the published data the humidity of the air was not allowed for. At the temperature at which ice formation is likely the fuel used in this country is not completely evaporated, and consequently the temperature drop depends on the proportion of the more volatile constituents in the fuel, or, in other words, on the earlier part of the boiling range. With more volatile fuel, such as is apparently used in America, the point of agreement may shift to later parts of the curve.

In reply to another speaker, Mr. Clothier stated that ice formation in carburettors is most severe at temperatures above those at which ice formation occurs on wings, and therefore icing of the carburettors is not necessarily an indication that ice formation will occur on the wings.

As suggested by Mr. Emtage and Mr. H. B. Taylor, the continually changing conditions in flight probably prevent the ice building up in sufficient quantity to cause trouble on many occasions when freezing conditions prevail. Flight tests with the ice detector used as an indicator have shown ice to be forming in the induction system on occasions when no fading of the engine could be detected. It has been recommended by more than one authority that to de-ice a carburettor all that is required is a few rapid accelerations of the engine resulting, if possible, in back fires. The intense vibration set up cracks the ice and it is blown off the surfaces. This would not appear to be a very safe procedure to adopt with supercharged engines fitted with suction carburettors, as the pieces of ice might damage the blower impeller.

Mr. Clothier was not sure that he could agree with Mr. Emtage that the cutting-out of an engine which sometimes occurred at 200 to 300ft. soon after take-off was due to ice formation, as unless the ice upsets distribution it can only cause a relatively gradual loss of engine power and although when conditions are right, ice can build up quickly, it is doubtful if it could do so rapidly

* Automotive Industries, Feb. 2nd, 1935, p. 135.

enough to shut the engine down in the time required to reach 200 to 300ft. Any serious ice formation during slow running would be noticed as a loss of power, if it had not already caused trouble, when the throttle was opened for take-off.

In reply to Mr. Narris, some data on the heat required to melt the ice in the choke tube is given in the American tests,[5] but in these tests no heat had been applied to the throttle butterfly, and if heat was to be used to prevent ice formation then the throttle must be heated. Mr. Clothier was not sure if an electric heater could be built into a throttle. Another difficulty with electric heating was the source of the current. If all the fuel of a 500 h.p. engine were to be evaporated about 13 k.w. would be required to be dissipated in the carburettor and induction system. Probably as a minimum 3 to 4 k.w. would be required, and of this at least 1 k.w. would have to be dissipated in the throttle butterflies.

In reply to Mr. Stern, only by locating the throttle before the point of entry of the fuel could ice be prevented from collecting on it, and even then there was a possibility of some ice forming at small throttle openings due to violent eddies above the throttle causing the fuel to bathe the back of the throttle butterfly. Moreover, moving the throttle position would not prevent ice forming on the walls of the induction pipe and other exposed parts.

Mr. Elliott's experience illustrates in an interesting manner the difficulty of preventing ice formation at small throttle openings, by the use of heated intake air.

The 589th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

An ordinary meeting of the Society was held in the Lecture Theatre of the Institution of Electrical Engineers, Victoria Embankment, London, W.C.2, on Friday, February 22nd, 1935, when a paper on "Research in the R.A.E. Tank," by Mr. L. P. Coombes, B.Sc., A.C.G.I., was presented and discussed.

In the Chair, Lt.-Col. J. T. C. Moore-Brabazon, President of the Society.

The CHAIRMAN: Mr. Coombes has had a very varied career. He was a pilot in No. 210 Squadron in France when that squadron was equipped with "Camels." Nowadays this squadron was a flying boat squadron. Mr. Coombes had later spent four years with the firm of Parsons, and afterwards had obtained a post in the wind-tunnel section at Farnborough. Later still, he was sent as Scientific Officer to the Marine Aircraft Experimental Establishment at Felixstowe, and had remained there until October, 1930. Earlier in his career, apparently, Mr. Coombes had spent some time in designing reinforced concrete structures; so that he seemed to have a very catholic knowledge of heavier and lighter things. He had returned to the R.A.E. to take charge of the new tank which had recently been built, and it was about the experiments in that tank that he would speak in his paper.

RESEARCH IN THE R.A.E. TANK

BY

L. P. COOMBES, B.Sc., A.C.G.I.

Introduction

Seaplane tank testing is an offshoot of ship tank testing, the technique of which was founded by William Froude nearly 70 years ago and is now highly developed. Apart from the fact that a scale model is towed through still water, however, there is little in common between the two systems of test, though one link remains in spite of dissentient voices; Froude's laws are used as the basis of correlation between model and full scale. In other respects, the conditions of operation of a ship and a seaplane on the water are so different that when the R.A.E. tank was built, the whole existing technique was reviewed.

The dimensions of the R.A.E. tank were fixed by a small committee who were appointed to deal with this problem in the light of the data available at that time, and the size of tank recommended by them is compared with the dimensions of two other tanks built abroad about the same time for testing seaplane models.

Tank.	Length. ft.	Width. ft.	Depth. ft.	Max. Speed of Carriage.
R.A.E., England	650	9	4.5	40 ft./sec.
H.S.V.A., Germany	1,050	16.5	8.3	66 ,,
N.A.C.A., U.S.A.	1,980	24	12	88 ,,

Consideration of this table shows that the sizes of the largest model it is possible to test in these three tanks is approximately in the ratio of 1 : 2 : 3.

Two immediate problems therefore awaited consideration. The first and more important was the calibration of the tank as regards the size of model it was possible to test, and to find what corrections, if any, were to be applied to the results in order to predict the performance of the full scale seaplane. The second problem was the review of existing methods of test in order to decide whether they were adequate, and if not, on what lines new technique should be developed.

During the constructional period, a good deal of thought was given to the measuring apparatus to be used. Nothing was known of the details of the foreign tanks, but after consideration of the systems employed at the N.P.L., Shorts' and Vickers' tanks, a four-wire suspension for the model was decided on. (In passing, it may be interesting to observe that the tank at Hamburg employs a system which is exactly similar in principle though the details differ. The R.A.E. and H.S.V.A. developed these systems quite independently.) Fig. 1 shows the general scheme of test. Two wires at the c.g. support the model laterally, while fore and aft wires determine the attitude in pitch. All four wires apply vertical forces, and for simplicity we can consider the two c.g. wires as counterbalancing the excess weight of the model while the fore and aft wires apply the wing lift and the pitching moment due to the wings, tailplane

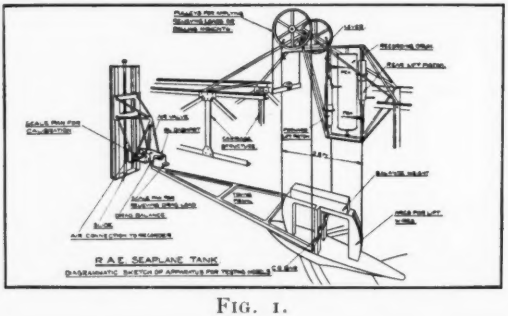

FIG. 1.

and thrust. The c.g. wires have counterbalance weights, while the fore and aft wires are attached to air pistons in which the air pressure can be accurately controlled. These pistons are air lubricated and work with very little friction. There are many advantages of this system. The weights to be handled are only a fraction of their normal value. The effective mass moving vertically with the model, and the moment of inertia of the model, are unchanged throughout the tests, so that a fair idea of behaviour can be obtained. Last, but by no means least, the damping in pitch due to constraint by the air pistons has a stabilising action on the models and it is possible to run even quite unstable models without the necessity of restraining the oscillations by hand—a process very likely to disturb the drag readings. The drag balance is also pneumatic. This has three advantages: (*a*) the recorder is independent of the balance, the connection being a flexible pipe; (*b*) the movements of the balance are so minute that they have no effect on the set-up of the model, so that there are no corrections to be applied to the readings; (*c*) a quick period balance and a highly magnified record are obtained without very refined workmanship.

Wall Interference

As soon as the balances were installed and working we attacked the problem of finding the limitations of the tank as regards size of model. Wall interference was measured first, and to save the expense of false walls, an image method was

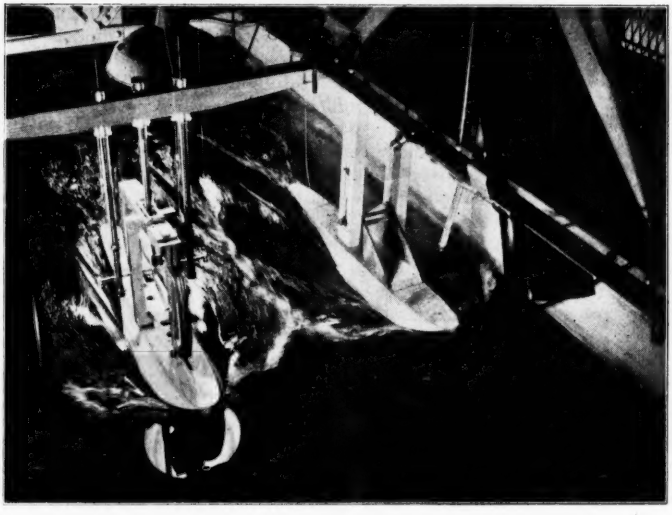

FIG. 2.
Wall interference tests.
Triple models under test at a speed of 12 knots (full scale).
Note.—One model is hidden by the carriage structure.

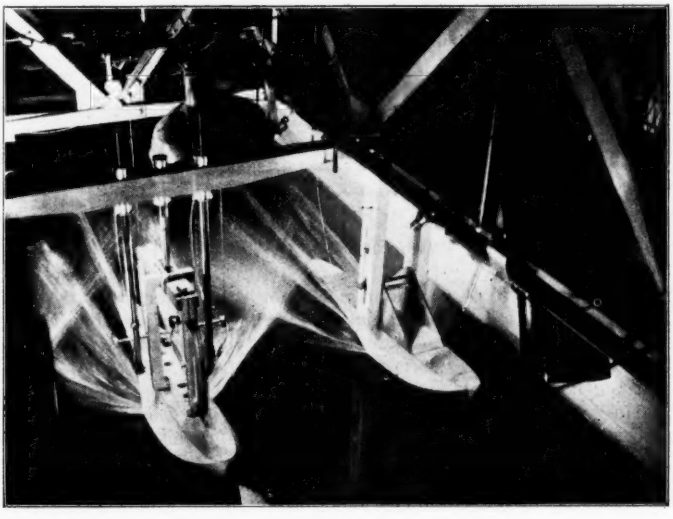

FIG. 3.
Wall interference tests.
Triple models under test at a speed of 52 knots.

employed. This was done by running first one, then two similar models abreast, spaced half the width of tank apart, and lastly, three similar models spaced one-third the width of tank apart. The effect, except for the very small tangential components of the velocity near the walls, should be equivalent to running the models in separate narrow channels, and as far as could be judged by observation, the effect was very successfully obtained except at high speeds when much spray was thrown up. At certain speeds spray from one model fell on its neighbour, but there did not seem to be any noticeable effect due to this cause, as the erection of screens between the models did not alter the measured resistance. Figs. 2 and 3 illustrate the tests and show the models at speeds of 12 and 52 knots (full scale). Two hulls were framed together and tested as a unit, but in the case of three hulls measurements were made on the centre hull only, the

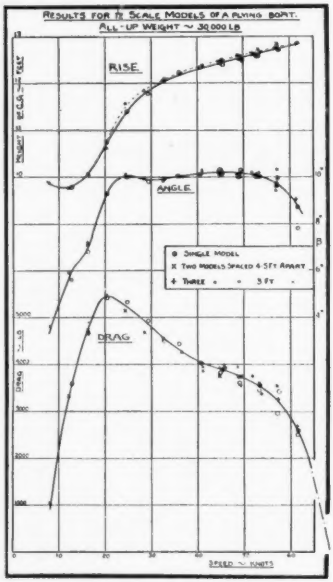

FIG. 4.
Typical results of wall interference tests.

other hulls being held fixed at the correct angle and immersion. The size of model used was 4.5 ft. long, *i.e.*, half the width of tank in length. The measurements were made in the normal manner, but one point must be emphasised. All the measurements made were corrected for air forces, *i.e.*, the air drag and air moment on the models were measured and subtracted from the total measured forces, leaving only the water forces to be compared. The models were first tested separately to check that they gave identical results. Typical results are shown in Fig. 4, which shows the measurements with no applied moment. There is some scattering of points, especially at high speeds, but these were due principally to errors of measurement and the instability of the hull form chosen. There was no evidence of any systematic differences in the measurements, except in the rise of the models. Here there is a small difference, the twin and triple models riding higher in the water than the single model. This effect reached a maximum at about 25 knots, which corresponded to the maximum speed of wave

translation in the tank. This pointed to the fact that it was really a depth effect. The tests showed that models up to 1.5 times the width of tank, *i.e.*, 13.5 ft. long, could be tested without side wall interference, provided that the water were as deep as the model was long. For twin floats spaced half their length apart, the limiting length would be slightly over 7 ft. Another inference from these tests is that twin floats can be spaced quite close together without mutual interference. The tests suggest no interference with a track of $\frac{2}{3}$ the length of the floats. This was later checked by tests on a twin-float model, and no interference was found with floats spaced less than $\frac{1}{2}$ their length apart.

Depth Effect

Depth effect was next investigated, though this problem only affected the tank indirectly, since the water was deeper—to scale—than the water flying boats usually operate in. It was of importance, because if there were any considerable

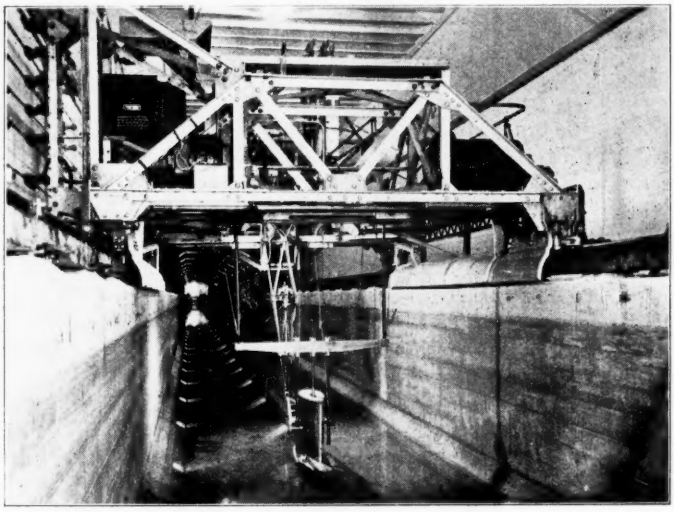

FIG. 5.
Depth effect tests.
View of model under test in 4in. of water.

effect due to depth it might be necessary to test models in the correct depth of water.

The tests were made on a 1/12 scale flying boat hull 4.5 ft. long and six depths of water were tried, varying from 54 ft. down to 4ft. full scale. This last depth left only a small clearance under the keel. The tests were made by lowering the water level in the tank, as this course was quicker and cheaper than fitting a false bottom. The R.A.E. apparatus is designed so that models may be tested in any depth of water. Fig. 5 shows the apparatus in use at a depth of 4 ins. of water. The wave formations were most interesting, especially near the critical speed given by $\sqrt{gh}$. At speeds below this, as is well known, a model forms two trains of waves, transverse and divergent, but when the model exceeds the limiting speed of wave propagation, the transverse waves can no longer be formed and only a divergent wave system is created. In the full depth of water the critical speed is 12 ft./sec., and at slightly higher speeds the trans-

verse waves were seen to disappear. At the quarter depth, at the critical speed of about 6 ft./sec., all the energy of transverse wave motion was concentrated in a solitary wave travelling with the model, which progressed by itself after the carriage stopped, and broke with a loud crash on the beach at the end of the tank. At smaller depths still, the model produced waves travelling faster than itself. The waves first formed abreast of the model and then travelled forward relative to the hull. This caused a slow oscillation in pitch and rise of the whole model. As the wave travelled forward of the model it increased in height and formed a cusped peak which finally broke. Meanwhile the cycle was being repeated, so that by the end of the run several such waves were travelling ahead of the model. Fig. 6 has been prepared from a cinema record to show the sequence of events. The disturbance was considerable, and débris at the bottom

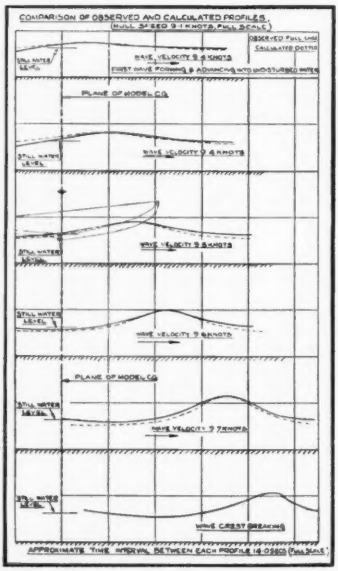
COMPARISON OF OBSERVED AND CALCULATED PROFILES.
(HULL AT SPEED 9·1 KNOTS, FULL SCALE.)
OBSERVED FULL LINE
CALCULATED DOTTED
STILL WATER LEVEL
WAVE VELOCITY 9·4 KNOTS
FIRST WAVE FORMING & ADVANCING INTO UNDISTURBED WATER
PLANE OF MODEL C.G.
WAVE VELOCITY 9·4 KNOTS
WAVE VELOCITY 9·2 KNOTS
WAVE VELOCITY 9 KNOTS
PLANE OF MODEL C.G.
WAVE VELOCITY 9 KNOTS
WAVE CREST BREAKING
APPROXIMATE TIME INTERVAL BETWEEN EACH PROFILE 14 SECS (FULL SCALE)

FIG. 6.

Depth effect tests.

Waves formed by a model in shallow water (wave profiles drawn from cinematograh records).

of the tank was in motion three or four model lengths ahead of the hull. The tests were repeated with triple models in half the depth, and these showed very much exaggerated depth effects, *i.e.*, the walls accentuated any depth effect, and, conversely, the model creating the largest waves would experience the greatest depth effect.

The practical application of the results is seen best from the figures where the measurements are plotted. Fig. 7 shows the drag measurements at low speeds. The zeroes of the curves have been displaced one square for clearness, and the critical speeds given by $\sqrt{gh}$ have been shown by arrows.

A small wave interference hump, unconnected with the depth, occurred in the curve for deep water. This hump can be traced in the other curves, but it was much modified by depth effects. At 13.5 ft. and lower depths the local

increases of drag were very considerable and occurred at speeds slightly in excess of $\sqrt{gh}$, due to the fact that the waves were of large amplitude and travelled faster than the speed given by $\sqrt{gh}$. The double curves show the extent of the periodic phenomena referred to. At higher speeds, the results at all depths were in good agreement. This is shown in Fig. 8, where the results at all depths for drag, rise and angle are plotted, and agree within the limits of experimental error. Speaking from the practical standpoint, it must be emphasised that the phenomena described occur at low speeds, and are not only very localised but take an appreciable time to build up. In the accelerated motion of a take-off, the effects will be considerably reduced, so that unless it were taxying at about the critical velocity, a flying boat would not experience any appreciable depth effects in taking off from shallow water.

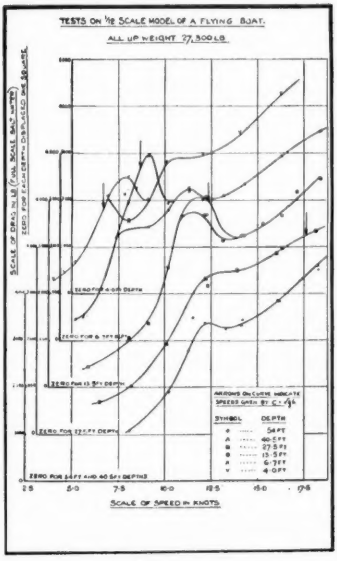

FIG. 7.
Depth effect tests.
Drag results at low speeds.

Scale Effect

Having determined that it was safe to test models up to 9 ft. long, three models were made to the same lines, these being 3, 4.5, and 9 ft. long, the corresponding scales being 1/18, 1/12 and 1/6 for a large flying boat. The same series of tests were carried out on each model. Fig. 9 shows some typical results. It is seen that scale effect is small at low and high speeds and reaches a maximum at the hump. One would expect such a result as scale effect usually reaches a maximum in any transitional stage of flow. Scale effect in tank testing can occur through skin friction or surface tension. It does not seem likely that surface tension can do more than alter the wetted area to a small extent and affect the spray thrown out, and on the assumption that skin friction was alone responsible, an attempt was made to calculate its effect. First, experiments were made to see whether there was any appreciable laminar flow present, but none could be detected. Then, assuming the flow to be fully turbulent, the skin friction drag was calculated at low speeds from observations of the wetted area.

At high speeds this was not possible, and the fact that the force on a planing surface can be split up into the tangential frictional drag and the pressure normal to the surface, was used. Fig. 10 shows the results of the calculation, and the agreement with the observed facts showed that the assumptions were not far wrong. The effect at the hump could not be calculated with our present lack of knowledge about this critical stage of the take-off. As a part of the scale effect research, the rivet heads, lap joints, chine angles, etc., which normally mar the smooth surface of a planing bottom, were represented to scale on the 1/6 scale model. A small increase of resistance throughout the speed range due to this cause was found, but the effect was so small as to be negligible in practice. This result accords with the small proportion of skin friction in the total drag calculated previously.

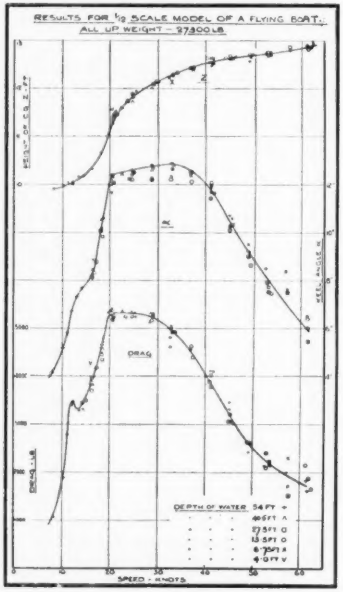

FIG. 8.
Depth effect tests.
Results at high speeds.

The final check on any model results is, of course, a comparison with full scale. Normally a full scale comparison is not easy to make because of the uncertainties of estimation of thrust, air drag, lift and slipstream effects. Fortunately we are in a better position, as there exists at Felixstowe a seaplane fitted with a force recording undercarriage capable of measuring the water forces on a large scale float. A 1/2.4 scale model hull to the same lines as the tank models has been constructed, and the results will be available for comparison in the near future.

Methods of Test

In the work so far described, the correlation of model and full scale results was based on Froude's laws, on the assumption that the wave-making resistance was the predominant factor. In the early stages of a take-off, there is no doubt

that this is so, but when the true planing condition is reached, certain people, *e.g.*, Schroeder in Germany, hold the opinion that the acceleration due to gravity is small compared with the acceleration of the water in the flow, and that the forces due to planing form a better basis of comparison. Later on, reference is made to an analysis by Mr. Perring, which showed that elementary planing surfaces can certainly be tested satisfactorily on such a basis. Complete hulls, too, bear this analysis satisfactorily as far as lift and drag are concerned, and the effects

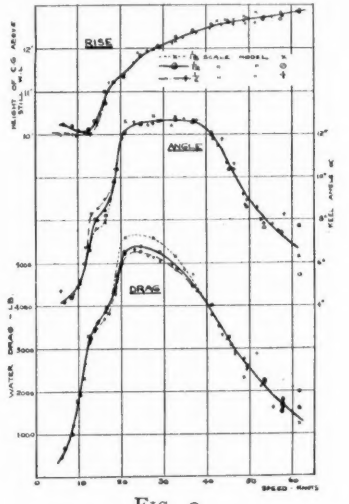

FIG. 9.

Scale effect tests.

Results for $^1/_{18}$, $^1/_{12}$ and $\frac{1}{6}$ scale models of a large flying boat.

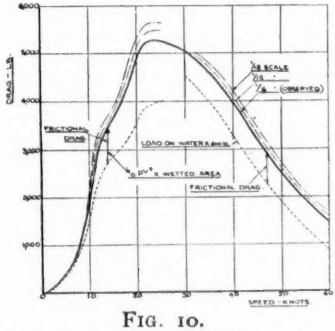

FIG. 10.

Calculated drag curves showing scale effect.

of changes in loading are thus readily calculable. When the second step enters the water, however, the moment relationships break down completely. In view of this fact, and also in view of the satisfactory scale effect comparison carried out on the basis of Froude's laws, it is proposed to adhere to the normal type of test until more evidence in favour of a change is forthcoming.

In the meanwhile, the position with regard to routine testing seemed fairly satisfactory, as every effort had been made to discover the limitations of the tank and apparatus. One major difference between tests in a tank and actual take-off conditions appeared worthy of study. This was the effect of acceleration on the forces. From full scale tests made at Felixstowe it appeared that the "virtual mass" effect was small, and probably negative, and theoretical considerations confirmed this view. It was considered desirable to make a certain number of tests in accelerated motion, not only to throw light on this point but also in order to develop a method of covering a range of speed in one run. This aspect will be referred to later on. In these tests we contented ourselves by doing each run at a fixed load on water, as it saved the large amount of work

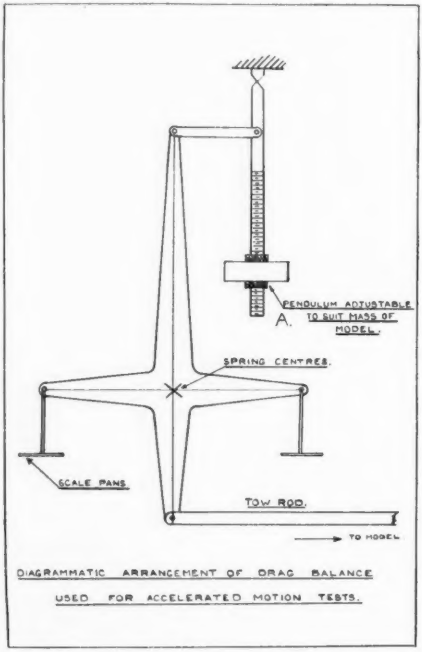

FIG. 11.

necessary to devise a method of applying lift varying as the attitude and the square of the speed. The drag in accelerated motion was measured by the aid of the device shown in Fig. 11. A pendulum A was connected by a system of levers to the drag balance. The length of this pendulum was adjustable, so that the effect of acceleration on it would be exactly equal and opposite to the effect on the mass of the model. The result was that the drag balance measured only the water drag, taking no account of the large forces needed to accelerate a heavy model. The results of these tests indicated that acceleration effects on drag and immersion are very small and can safely be neglected. The effect on the moments was of some importance, but it is intended to make a more representative test with a complete dynamic model to check this point.

With regard to technique, what factors should be taken into account in testing a model? To be accurate, one should apply to the model the lift due to the wings and tail, taking into account the angle and square of the speed,

together with slipstream and ground effects. From the measured drag must be subtracted the air drag of model and gear, and, from the moments, the air moments. These corrections are of importance at high speeds. The question of thrust moments is a vexed one. It is our practice, and we believe it to be right, to tow through the c.g. and not through the thrust line. In actual fact the thrust moment is offset by slipstream effects, being entirely balanced at the moment of take-off. We prefer to calculate thrust moments and apply them with the air pitching moments.

FIG. 12.

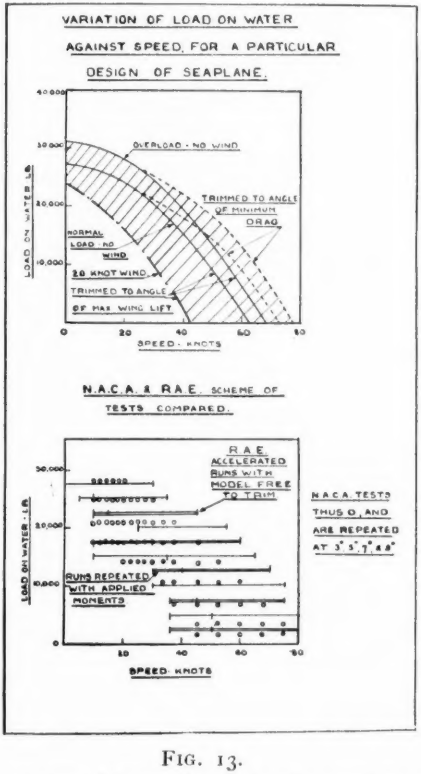
VARIATION OF LOAD ON WATER
AGAINST SPEED, FOR A PARTICULAR
DESIGN OF SEAPLANE.
OVERLOAD - NO WIND
TRIMMED TO ANGLE OF MINIMUM DRAG
NORMAL LOAD NO WIND
20 KNOT WIND
TRIMMED TO ANGLE OF MAX WING LIFT
LOAD ON WATER - LB
SPEED - KNOTS
N.A.C.A. & R.A.E. SCHEME OF TESTS COMPARED.
R.A.E. ACCELERATED RUNS WITH MODEL FREE TO TRIM
RUNS REPEATED WITH APPLIED MOMENTS
N.A.C.A. TESTS THUS O, AND ARE REPEATED AT 3°, 5°, 7°, 9°
LOAD ON WATER - LB
SPEED KNOTS

FIG. 13.

Scheme for complete routine tests of a seaplane model.

It might be useful to say something about routine testing. A seaplane starts from rest at a certain all-up weight, and, after accelerating, leaves the water at a take-off speed varying with the conditions. The load on water varies from the initial weight at zero speed to no load at the take-off speed, in some manner depending on the trim, wing area, wind speed, etc. In practice, if it is wished to take into account changes of loading, wing, area, wind speed, and other factors, it is necessary to cover the shaded area shown in the diagram of Fig. 12, and further, this area must be explored at various angles of trim. The Langley field tank of the N.A.C.A. have developed a system whereby this area is mapped out by a series of 70 runs shown as spots on the next diagram (Fig. 13). These runs are made at four different angles, *i.e.*, a total of 280 runs. They have

also introduced a system of plotting to simplify the use of the results. The result is that any air-structure can be designed in combination with the hull. As an experiment, we covered the same ground for one particular model by a series of accelerated runs shown as lines in the same figure, so that the same amount of information was collected in about 30 runs. The results were checked against runs in steady motion, and the agreement found was good. The computational labour involved in such a method, except where the design is of exceptional interest, is unwarranted, as approximate answers can be obtained from much more limited data by calculation. On the whole, the more normal type of test is preferable in most cases.

FIG. 14.

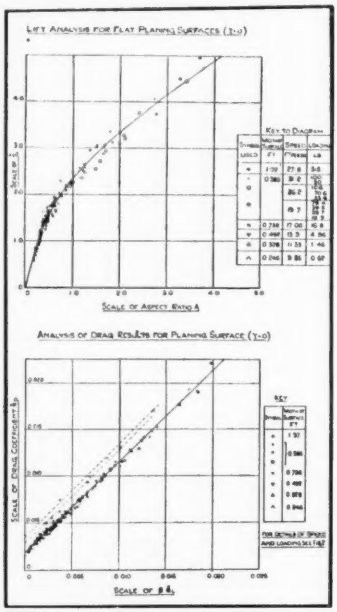
LIFT ANALYSIS FOR FLAT PLANING SURFACES (1:0)
KEY TO DIAGRAM
SCALE OF ASPECT RATIO A
ANALYSIS OF DRAG RESULTS FOR PLANING SURFACE (1:0)
KEY
SCALE OF βA

FIG. 14a.

Lift and drag analysis for flat planing surfaces.

These tests completed the first phase of tank research, that is:—

(*a*) The exploration of the tank limitations with regard to size of model, and the accuracy of results for estimating full scale performance.

(*b*) Examination of existing methods of test with a view to developing new methods if necessary.

Improvement of Hull Design

The tank has been in operation for just on two years, and the basic research work just described, together with the considerable proportion of time spent on development work, have not left much time for progress as yet. In my opinion, improvement of design will only follow systematic tests of families of models, as the data obtained from *ad hoc* tests is not in a convenient form for analysis. The Americans have taken the lead in this direction, but their

first efforts have not been completely successful, as the changes in the variable under consideration were obscured by changes in other important variables. The Germans attacked the problem more fundamentally with tests on elementary planing surfaces with cross sections similar to flying boat hulls, and similar tests were made at the N.P.L. The analysis of these results were carried out by Mr. Perring and Mr. Johnston of the R.A.E. tank, and they showed that surfaces planing over water obey very similar laws to aerofoils, and the forces are

FIG. 15.

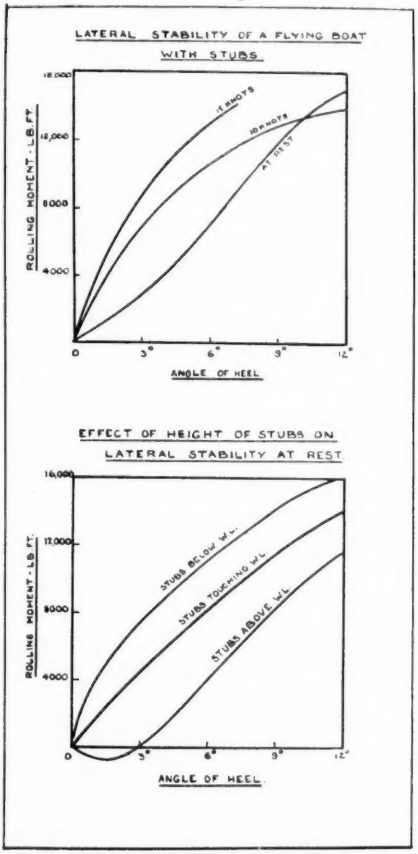

FIG. 16.

Effect of stubs on the lateral stability of a flying boat.

calculable. Figs. 14 and 14*a* have been reproduced from their report. Fig. 14 shows how the slope of the lift curve and aspect ratio bear an unique relationship, independent of size and loading of the planing surface, and Fig. 14*a* shows that k_L and k_D are connected by the relation $k_{D0} + \alpha k_L$. For very small surfaces, scale effect alters the value of k_{D0}, but this was shown to be a function of Reynolds number. The moment data were also successfully analysed. The relationships break down for a hull when the second step enters the water, and work on two

elementary surfaces in tandem was to have been done at the N.P.L. but has been unavoidably held up.

One investigation which was carried out, and which is of general interest, was on stubs or sponsons for the lateral stabilisation of hulls on the water. Experience with these stabilisers is very limited in this country, and only one flying boat has actually been built and flown with them. The investigation started with stubs of the Dornier type, which were tested on two hulls of similar design, one having rather flat vee sections following Dornier's design, and the other

FIG. 17.

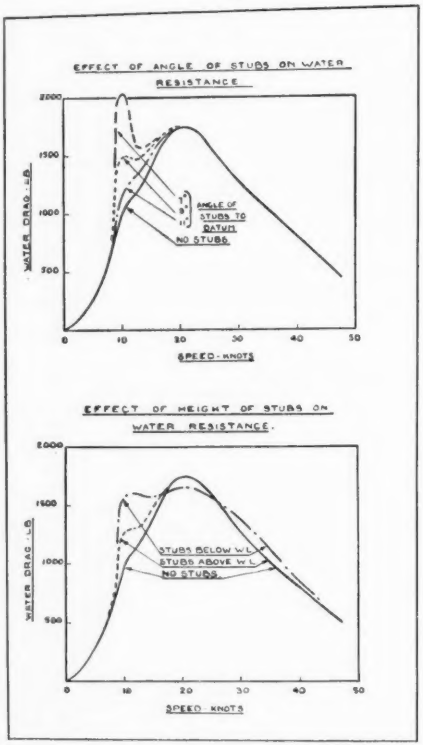
EFFECT OF ANGLE OF STUBS ON WATER RESISTANCE.
WATER DRAG - LB.
SPEED - KNOTS
ANGLE OF STUBS TO DATUM
NO STUBS
EFFECT OF HEIGHT OF STUBS ON WATER RESISTANCE.
WATER DRAG - LB.
SPEED KNOTS
STUBS BELOW W.L.
STUBS ABOVE W.L.
NO STUBS

FIG. 18.

Effect of stubs on the water drag of a flying boat.

having more acute angles in conformity with British practice. These tests showed that there was no inherent reason why stubs should not be successful on quite deep vee-bottomed hulls, and further investigations were carried out with this hull only, as the flatter hull appeared to have disadvantages from a stability and impact point of view. It was found that the general characteristic of stubs is that they interfere markedly with the bow wave system at a speed of about 10 to 14 knots, and so introduce a wave interference hump into the resistance curve. This secondary hump with badly placed stubs may be a great deal higher than the normal hump resistance.

The first tests were made to find the effect of position of stubs which were attached at various fore and aft positions, while the height above or below the water line, and the angle of attack were also varied. Typical results are shown in Figs. 15 to 18. The first graph shows how the lateral stability curve becomes steeper as the speed increases, though there is a tendency for the hull in motion to become unstable at a lower limiting moment than the hull at rest. The lower picture shows how very important the height of stub is from a lateral stability point of view. If placed above the water line, the hull is initially unstable. If the effect of sudden side gusts is taken into account, the dynamical stability must be calculated. This is defined as the work done on the hull to roll it to any given angle and is the area under the normal stability curve. Under such

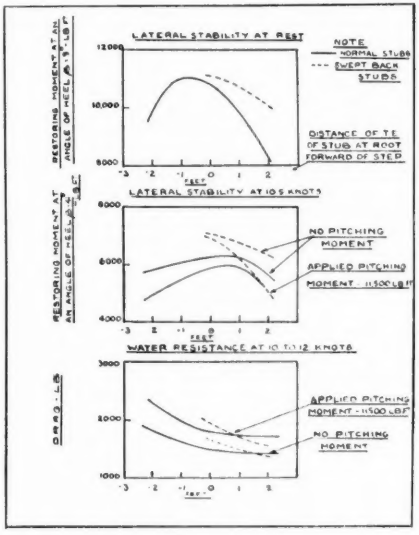
LATERAL STABILITY AT REST
NOTE
NORMAL STUBS
SWEPT BACK STUBS
DISTANCE OF T.E. OF STUB AT ROOT FORWARD OF STEP
FEET
LATERAL STABILITY AT 10.5 KNOTS
NO PITCHING MOMENT
APPLIED PITCHING MOMENT 11500 LB.FT
WATER RESISTANCE AT 10.7-12 KNOTS
APPLIED PITCHING MOMENT - 11500 LBS.
NO PITCHING MOMENT

FIG. 19.

Effect of fore and aft position of stubs on drag and lateral stability of a flying boat.

circumstances a stub placed above the water line appears to a very much greater disadvantage. The next two figures (Figs. 17 and 18) show the effects of angle and height on resistance and illustrate how a stub at too small an angle produces a secondary hump greater than the main hump resistance. The effect of a stub below the water line is to produce an elongated resistance hump which may actually reduce the normal hump resistance. Space does not permit all the various factors to be illustrated, but one more figure will serve to show the general situation. In Fig. 19 the effect of fore and aft position is shown by a set of cross plots, and it is clear that the best setting of the stubs is a compromise between low resistance (which demands a position well forward, and a setting above the water line and at a large angle of attack) and lateral stability, which requires a medium position and angular setting, and a height somewhat below the water line. It seemed that a better compromise might be obtained by sweeping back the stubs in plan form, and the effect of this is shown by the dotted curves. Other factors in stub design were varied, as for example the span, camber of section, positive and negative, and dihedral, so giving a fairly

general survey of the problem. Lastly, the modifications tested in the tank were tried in the wind tunnel to find their effect on air performance, as air drag is one of the main objections to stubs. The next figure (Fig. 20) shows the general trend of results. It shows that the actual position of the stubs has only a minor effect on the top speed, the variations due to this cause being about ± 1 m.p.h. The curve without stubs has been shown, and the approximate drag due to wing floats added. This curve would indicate that the penalty for fitting stubs as against wing tip floats on this design is about $2\frac{1}{2}$ m.p.h., but it is possible that the main wing area for a stub design can be reduced if the stubs are so placed as to give a certain amount of lift at high angles of attack. Under very favourable circumstances the stub design may even have a lower drag and a slightly higher speed. The greatest improvement in the air drag of stubs is undoubtedly achieved by better aerodynamic design, and by fining down the trailing edge as far as possible consistent with strength. The big effect of even a small amount of fairing is clearly indicated.

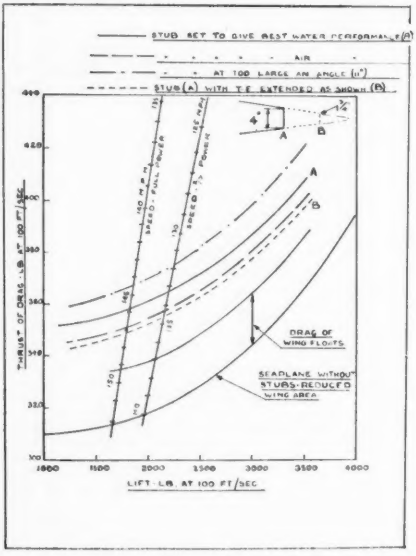

FIG. 20.

Effect of stubs on the air performance of a flying boat.

Porpoising

I now come to the last phase of our activities: longitudinal instability or porpoising. This is still a problem for the designer, as up to now no hard and fast rules for its avoidance have been laid down. At the R.A.E. the problem was attacked from two points of view—analytically and experimentally—at the same time so as to see which avenue of approach would prove more profitable. The mathematical side was developed by Perring and Glauert, and an analysis made on similar lines to those used for aeroplane stability except that the absolute height relative to the water surface had to be taken into account. In the mathematical work, the stability derivatives were calculated from the very much simplified assumption that the planing surfaces were flat planes without mutual interference. Using these calculated values the effect of certain changes in hull

design were tried, but the conclusions were only partly borne out by experience. It was obvious that the assumptions made were too crude, and that before any extensive mathematical survey could be made, the derivatives would have to be measured for actual hulls. An oscillating balance has been designed and constructed for this purpose, and in the meanwhile the mathematical work has been suspended till the necessary stability data are available.

However, the analysis yielded one very useful conclusion: that longitudinal freedom affected the motion to a negligible extent, and this fact was first checked experimentally and then made use of in designing a fitting for towing dynamic models.

Another fact which emerged from the theory was that model experiments could not be relied upon unless the air structure was represented. Dynamically similar models complete with wings and tailplane of approximately the correct

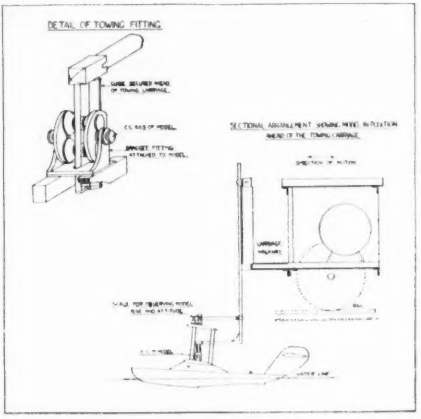

FIG. 21.

Details of the mechanical guide used for porpoising tests of dynamic models.

proportions are therefore used. The models are made of balsa wood, waterproofed and strengthened as necessary, and are of the correct mass and moment of inertia. They are towed by a special fitting which allows freedom in rise and pitch, but prevents yawing or rolling (Fig. 21). A typical model is illustrated in Fig. 22. The technique of making and testing such models has been developed so that any important design can be tested in the model stage and, if necessary, alterations made in order to eradicate any tendency to instability. In the course of testing these models it has been found that seaplanes have a certain range of angles within which they are stable (see Fig. 23). If trimmed too far nose down or tail down, porpoising occurs. These angular limits vary with speed, but are well defined as a rule, and do not alter much with change of c.g. position, loading or moment of inertia. This enormously simplifies the testing, which has been reduced to a relatively simple routine. The value of this dynamic model test is fully apparent when an unorthodox design is under consideration. As an extreme example I might quote a recent proposal for a large tailless flying boat having a pterodactyl wing plus stubs, a combination of two experimental features. In the course of the tests, we have discovered a few interesting facts about porpoising and its amelioration, but not enough to warrant laying down rules for success. Here is another case where systematic changes as opposed to *ad hoc* tests are desirable, and it is hoped to have time in the near future to start such

a series. So far, we have had very little opportunity to compare the results predicted from models with the full-scale behaviour, but where this has been done the agreement between model and full-scale is good.

Seaworthiness tests in a train of waves demand a similar technique to porpoising, and dynamic models are necessary. A wave maker has been installed in the R.A.E. tank and experiments in this direction have been commenced.

Another interesting use of dynamic models was in an experiment made in connection with a proposal for impact tests on hulls. By photographing in slow motion the impact of a model in which various alterations were made, *e.g.*, the air structure removed and lift applied by weights, moment of inertia altered, no lift applied, etc., it was possible to say what type of test was desirable in order to give approximately the right motion after impact.

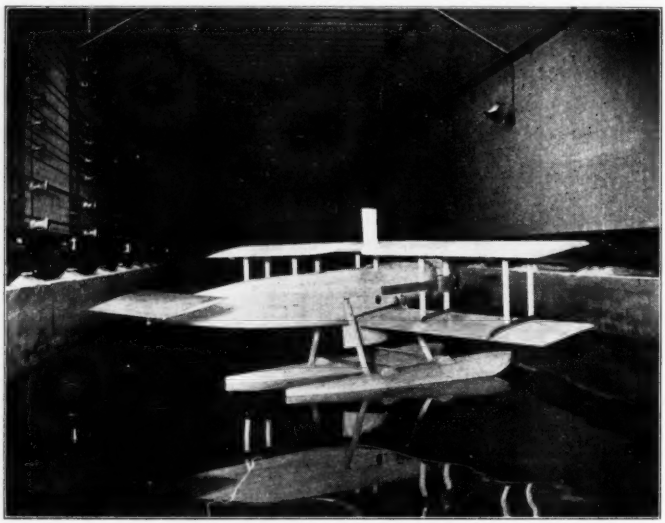

FIG. 22.

A dynamic model of a twin-float seaplane.

Future Research

A few words should be said with regard to the work contemplated. Several designers have expressed the view that the unstable yawing moments on certain types of hulls should be investigated. At the same time yawing moments at low speeds are required for water rudder tests and we are therefore designing a balance to measure yawing moments. The same apparatus will measure rolling moments more satisfactorily than the present crude arrangement and further systematic tests on lateral stabilisers will be made.

Experiments on changes in hull design in order to improve efficiency have commenced. Some of the changes contemplated are in the direction of unorthodox hull forms, but the effect of altering standard types will also be tried. The study of porpoising is going forward by both analytical and experimental methods. The analysis depends on the evaluation of the stability derivatives and this is in hand. The most profitable field for experiment is an investigation on dynamic models in which the effect of systematic changes in hull design are correlated with their effects on stability.

In all the foregoing discussion, I have made no reference to development tests, though a large proportion of the tank time is devoted to these. The reasons are obvious, as the results are in general confidential and applicable only to the particular design under test. The research methods described are frequently used ultimately in routine tests, as in the case of porpoising where a large proportion of new designs are constructed as dynamic models in order to assess their stability.

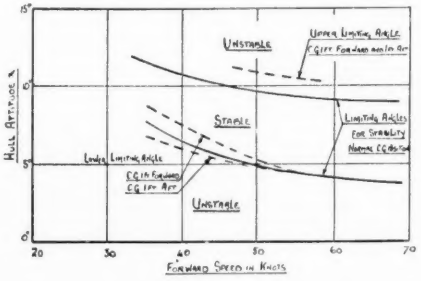

FIG. 23.

Porpoising tests.

Curves showing the effect of longitudinal position of centre of gravity upon the stability of a dynamic model of a boat seaplane.

Conclusion

I have endeavoured to give a summary of the research work of the R.A.E. tank, and so that any listener who is interested in a particular item can obtain more detailed information, references are given at the end of the text. I felt that this course was the best as it affords an indication of the direction in which research is proceeding, without confusing the issue with too much detail.

In conclusion, I wish to thank the Air Ministry for permission to utilise the data of this lecture, though any opinions expressed are my own. I should also like to take this opportunity of expressing my warmest appreciation of the work of the other members of the tank staff.

Author.	*Title.*
L. P. Coombes and W. G. A. Perring.	Wall Interference and Depth.
D. W. Bottle and L. Johnston.	Effect in the R.A.E. Seaplane Tank and Scale Effect Tests on Hulls of three sizes. R. & M. 1649, February, 1935.
W. G. A. Perring and L. Johnston.	The Hydrodynamic Forces and Moments of a Simple Planing Surface and an Analysis of the Hydrodynamic Forces and Moments on a Flying Boat Hull. R. & M. 1646, February, 1935.
P. Schroeder.	Application of a New Hydrodynamical Reduction Theorem in the Investigation of the Take-off of Seaplanes. Z.F.M., January 14th, 1931.
Shoemaker and Parkinson.	Tank Tests of a Family of Flying-boat Hulls. N.A.C.A. Technical Note No. 491, February, 1934.
Sottorf.	Versuche mit Gleitflachen. Werft Reederei Hafen. Nov., 1929; Oct., 1932; Feb., 1933; and March, 1933.
W. G. A. Perring and H. Glauert.	Stability on the Water of a Seaplane in the Planing condition. R. & M. 1493, September, 1932.

Discussion

Mr. H. E. Wimperis (Director of Scientific Research, Air Ministry, *Fellow, Vice-President*) took the chair at the opening of the discussion:—

Mr. Coombes' paper was not only very interesting, but also very important, because it described for the first time the nature of the calibration tests which had been made on the new tank at Farnborough. Naturally, those calibration tests had had to be made as soon as the tank was ready for service, so that the experimenters should be able to interpret the results obtained. Mr. Coombes had indicated what were the anticipations of the small sub-committee of the Aeronautical Research Committee which had advised the Air Ministry concerning the construction of the tank, and it was very gratifying that the foresight of the members of that sub-committee had enabled them to predict the degree of accuracy that would be obtainable in seaplane model testing in a tank of the dimensions contemplated. Mr. Wimperis was one of the members of the sub-committee, and he recalled that they had felt a certain responsibility because they were advising the construction of a tank a good deal smaller than those which other countries were known to be contemplating. Its cubic capacity was only one-twentieth of that of the new American tank at Langley Field, for instance. But there was no point in building a tank bigger and more costly, and slower to work, than circumstances really required, and the sub-committee had considered that a 5 per cent. degree of accuracy, which was all that was wanted, would be obtained in a tank of the dimensions decided upon. Mr. Coombes had spoken of the measurements made by the Farnborough staff, and had shown that the predictions of the sub-committee had been justified in the results—an important conclusion.

Inviting Mr. Gouge to take part in the discussion, Mr. Wimperis said it was due to the initiative of Mr. Gouge's firm, who had built the first of these small seaplane model testing tanks, that the attention of the Aeronautical Research Committee had been drawn to the possibility of securing the information required from these small tanks.

Mr. A. Gouge (*Fellow*): The Director of Scientific Research must feel satisfied by the amount of research that had been carried out in the tank in the comparatively short time during which it had been operating.

With regard to the use of sponsons or stubs, he had understood Mr. Coombes to say that one could reckon on some aerodynamic lift from the stub. Perhaps one could, but it would appear that the resistance curve shown had taken that fully into account, as the stub was on the model tested.

Mr. Gouge also asked whether research had been carried out on the effect of the vertical component of the propeller thrust upon longitudinal stability at high speeds, *i.e.*, porpoising. Some tests carried out on models recently had indicated that that was a big item. It made a marked difference to the rise of the model and a marked difference to the resistance, and as it lifted the model more out of the water it seemed that it might have other effects on the stability—detrimental or otherwise.

Mr. J. S. Buchanan (*Fellow*): Having commented upon the intense interest of the subject to all engaged in the design of seaplanes, he congratulated the Aeronautical Research Committee on their foresight in providing a small tank, which had proved very adequate for all the work that had to be done, so saving very much public money.

Discussing frictional resistance as against surface tension, he asked if the author could explain the fact that, with a very flat calm on an oily surface, the length of run of a seaplane of any kind to take off was increased out of all reasonable proportion to the resistance as measured in a tank model. It seemed to Major Buchanan that that could only be attributed to the facts that the surface of the water was unbroken and that the surface tension of the water materially retarded the take-off.

Commenting on the curve showing the lateral stability of seaplanes fitted with sponsons, he recalled that early experiences of the use of devices of this kind were not very encouraging, because it was found that at certain speeds on the water lateral instability of the seaplanes as a whole did result. The curves in the paper did not appear to show that effect in any way. He wondered whether there was any natural lateral instability of the sponsons themselves under certain water conditions, either submerged or semi-submerged; *i.e.*, whether, when a seaplane heeled over and the sponson on one side became submerged, there was a tendency for the seaplane to continue to heel over, due to the water forces alone. He did not know whether work had been done on this problem at the R.A.E. tank, but in some cases considerable difficulty had been experienced in experimenting with seaplanes at full scale.

From the point of view of the development of the aeroplane, the R.A.E. had been looking forward for many years to having a tank of its own, and it was hoped and believed that the provision of the tank constituted a big step towards the rapid development of aeroplanes of this kind in this country. He paid a tribute to Mr. Coombes for the lucidity with which he had summarised the work done at Farnborough.

Professor G. T. R. Hill (*Fellow*): Even in the R.A.E. tank, which was small relative to the tanks used abroad, the dynamic models were quite big; the photographs indicated that the models were nearly as wide as the tank itself, and they were models of remarkable beauty of workmanship and accuracy, considering the extraordinarily light weight to which they had to be reduced.

Professor Hill felt that there was a prejudice in this country against the use of stubs or sponsons, and this view was not really founded on exact knowledge. The tests carried out with them were encouraging, and the fact that the stubs added to the aerodynamic lift was of very real advantage; not only did they add directly to the lift by reason of the forces acting on the stub surfaces themselves, but in certain cases favourable interference effects were shown, and these two factors together made the picture look appreciably different from a bare comparison of the water results.

Commenting on the references made to the degree of accuracy obtained in model tests in the small tank, Prof. Hill asked whether comparable tests had been made with models both in the R.A.E. tank and in the larger tanks either in Germany or the United States, and whether Mr. Coombes considered that such tests would be worth while. The results of such tests might give confidence to, among others, the unscientific—and very often the unscientific held the moneybags.

Mr. H. M. Garner (M.A.E.E., Felixstowe, *Fellow*): Mr. Coombes could claim to have proved fairly and squarely all the points, with perhaps one exception, with regard to the calibration of the tank. The exception was the scale effect at high speeds. The accuracy of measurement of resistance at high speeds was lower than the accuracy of measurement at lower speeds; that was indicated in all the curves shown, and one should be grateful to Mr. Coombes for having given all the observed points. Mr. Garner emphasised that he was not making a criticism of the R.A.E. tank in particular; the difficulty applied to all tank experiments. It was very important to bear in mind that the standard of accuracy of measurement was reduced very considerably at high speeds, because in the future they should find more and more that heavily-loaded flying boats would tend to stick at high speeds rather than at low speeds. An improvement in the measurement of resistance at high speed would be of very real help in determining more accurately the take-off performance. Some tests were being made at Felixstowe on half-scale models of flying boat hulls attached to a small seaplane, and he hoped that the results of that work would throw some light on the scale effect, particularly at high speeds.

The work on stubs was most useful, and this was the first occasion on which any information had been made available from a series of tests on the effect of moving the stubs from one position to another on the hull of a flying boat. Mr. Coombes was to be congratulated on having found a type of stub which, when placed in the optimum position, did not affect the resistance of the hull at hump speeds and increased the resistance only very slightly at speeds below the hump—an increase of no practical importance. Mr. Garner asked what was the top speed of the flying boat of which the speed was reduced by $2\frac{1}{2}$ m.p.h. by the fitting of stubs, and secondly, whether the wing-tip floats and stubs were chosen to give the same lateral stability.

Mr. H. E. WIMPERIS (*Fellow*): Mr. Coombes might have stated, he thought quite truthfully, that the endeavour to measure the porpoising qualities of a flying boat by making tests on a dynamic model was made first in this country. So far as Mr. Wimperis was aware, no previous work on these lines had been done anywhere; and if that were true, it was much to the credit of the Farnborough staff. In much the same way, dynamic models of aeroplanes were first used in the vertical spinning tunnel at Farnborough in order to determine in advance the spinning qualities of aeroplanes it was proposed to construct. There had not yet been time to check the results obtained on models at Farnborough by full-scale results at Felixstowe, except in one or two cases, but those one or two cases indicated that the models were slightly pessimistic. If the results obtained with a model were all right, one might be quite sure, on present indications, that the full-scale machine would also be all right. If there were to be any divergence as between the model and full-scale results, one naturally preferred that the models should be pessimistic.

When the R.A.E. tank had become available he had been very desirous that a study should be made of stubs in comparison with floats, in so far as such a study could be made in a tank, because he had felt that not nearly enough work had been done in this country on that matter. Whatever they might think ought to be the case, aircraft design did go very much by fashion. There was a time when the biplane was the universal fashion in this country; but at the moment that position was being almost reversed. Similarly, there was a time when everyone had favoured wing-tip floats and had looked down upon stub floats; it seemed, however, that the pendulum was having a decided motion in the opposite direction—and a direction with which he personally had very much sympathy.

Discussing the method of presenting results of tank experiments, Mr. Wimperis said he appreciated that the method used by Mr. Coombes was the traditional method, sanctioned by many years' experience of naval architects, whereby the figures represented on the diagrams for drag and lift were purely fictitious figures—not the actual figures as measured, but figures which were thought to represent the results on the full-scale machine, on the assumption that Froude's law applied. That law did apply, or it very nearly applied; but, after all, it could not be absolutely correct. There were certain differences between seaplane behaviour and ship behaviour which rendered the case a little different, and he personally would feel a little happier—this was a personal and not an official opinion—if the forces and speeds were represented as measured on the models. He would not mind if the figures that were deduced on the assumption that Froude's law applied were shown also, but he would like to see the actual figures as well. He believed that practice was followed in presenting the results obtained in the new tank at Ottawa, and he asked Mr. Coombes to express his opinion whether or not it would be better to give the actual figures instead of the deduced figures. Mr. Wimperis felt just as strongly about that as he did about the desirability of entering up the observations on the curves, as in the case of almost every curve exhibited by Mr. Coombes. This, again, was somewhat a break from the old practice of the naval architects,

who so very often show faired curves; faired curves did not give one much idea as to the accuracy of the results.

Finally, Mr. Wimperis endorsed Mr. Hill's remarks in thanking Mr. Coombes for the particularly lucid way in which he had dealt with a highly technical subject.

Mr. W. G. A. PERRING (*Associate Fellow*): He would like to add a little information in connection with Figs. 14 and 14*a*, which, he said, struck at the root of the Froude law so far as seaplane testing was concerned. The figures represented the results of a series of tests on planing surfaces, but the relationships for flat planing surfaces exhibited by the curves in these figures applied equally well to wedge-shaped planing surfaces. The coefficients employed were similar to the familiar lift and drag coefficients used in aeronautics, and the curves established the connection between the lift, drag, and speed for plates of any size and loading. The implication of the results was that tests on any planing surface could be extended and applied to other conditions of loading and speed without regard to the Froude law which, of course, requires that the tests be made at the corresponding speed and corresponding loading. This might appear to be a very bold step, and to investigate it, the forces on a seaplane hull, tested over a large range of displacement, roughly from 8,000lb. to 32,000lb., were analysed by plotting drag/speed^2 against lift/speed^2. It was found that all the experimental results at any given incidence fell on a common line, and, in general, it was found that one could depart a good deal from Froude's law and still be substantially correct.

The seaplane results differed in one important respect from the results shown in Figs. 14 and 14*a* of the paper. It could not longer be assumed that

$$k_D = k_{D0} + \alpha k_L$$

but instead

$$k_D = k_{D0} + \beta k_L$$

where β still depended on the attitude, represented the seaplane results. β approximated to α at large planing angles, but fell away less rapidly as the planing angle became small. The reason for this is, no doubt, due to the complicated shape of the underwater form of a seaplane, and is probably largely due to the longitudinal curvature of the form. With simple planing surfaces having longitudinal curvature it has been found that the curvature effect was similar to the effect of camber in the case of an aerofoil.

With regard to porpoising, a commencement on the correlation of the model and full-scale results was beginning, and Mr. Perring agreed with Mr. Wimperis that possibly the model results were a trifle pessimistic, although the latest evidence indicated almost exact agreement between the model and full scale.

Mr. J. H. LOWER (Messrs. Short Bros., *Associate Fellow*): Referring to the method of testing at the R.A.E. tank, was the author quite correct in stating that the air pistons to which the fore and aft wires of the model were attached had a stabilising effect and was it possible to run even quite unstable models without the necessity of restraining the oscillations by hand? He personally had imagined that a model might run with a sort of paddling motion at the after end, due to the waves formed at the fore end hitting the after end, and that the wires would become slack and taut alternately.

As to wall interference, he was not clear about the claim that by running models side by side one would produce exactly the same effect as by running a single model and having the waves rolling at an angle and hitting the side of the tank wall. The author had mentioned that he had used a screen by which he could check up his conclusions, but Mr. Lower was not sure that a screen would give exactly the same effect as a wall, because one had to consider not only the surface portion of the wave cast from the model but also a wave underneath, of solid water, which had also to rebound against the solid wall.

With regard to the recorded rise of the models, as shown in Fig. 6, the inference was that in a narrow tank the recorded rise was relatively higher. That was not quite in agreement with some results, of which he believed Mr. Coombes was aware, obtained in comparative tests in tanks of varying width, at the R.A.E., the N.P.L. and at Ottawa, showing that in the narrowest tank the lowest rise was recorded—the difference was small, but the consistency was there. The lack of agreement between the results shown in Fig. 6 and the results of the comparative tests could not be attributed to the apparatus, because measurement of rise was quite a simple matter.

With regard to twin float spacing, and Mr. Coombes' statement that he could place the models reasonably close together without producing any appreciable interference effect, Mr. Lower said that on one occasion it had been reported to his company that a certain machine, having floats spaced fairly wide apart, had to be altered, for structural reasons, and the floats were brought closer together; it was found that there was definitely less resistance, despite the fact that the floats were not so far apart. His company would not believe it at first, but some tests were made on models, with the float spacing modified, and the same result was obtained. He did not know whether the interference between the floats tended to raise the model out of the water, but they had recorded less resistance—at least, with the particular floats used in that case.

Discussing scale effect, Mr. Lower was not quite in agreement with the view that smaller models recorded higher resistance than larger ones, because some recent comparative tests, of which Mr. Coombes was also aware, had shown that larger models gave greater resistance records, at the higher speeds particularly; at the hump the difference was not so pronounced.

Finally, Mr. Lower expressed appreciation of the work that had been done in the R.A.E. tank, and looked forward to being able to secure further help and advice from the R.A.E. Some of its work had confirmed various assumptions that earlier workers had made, so that these could take some credit for their original work.

Professor S. Ober (Associate Professor in the Aeronautics Department of the Massachusetts Institute of Technology and in charge of the wind tunnel research work) (*communicated*): Would Mr. Coombes be willing to add to his paper some detail of the exact method of the use of the pneumatic cylinders on the fore and aft wires to supply the wing lift. Is the wing lift assumed to vary as the square of the speed, or is the effect of the inclination of the wing system considered? What source is used for the compressed air?

The method used in determining the lack of measurable interference of the tank wall on the behaviour is exact only if the interference is negligible; two models side by side in open water give in a potential flow the effect of one and a single wall, but three models side by side do not give the effect of one between two walls on account of the interference between the flow patterns of the outer pair. If however the presence of the outer pair does not change the resistance of the original, perhaps the conclusion may be justified that midway from the inner to each of the outer pair a wall would cause no interference.

The research on stubs is welcomed, as this arrangement probably is more seaworthy than that with wing-tip floats in a moderate sea. The statement that under favourable circumstances the high speed of a boat with stubs may be more than with wing-tip floats is particularly interesting in view of the claim of the Glen L. Martin Co. that their "Clipper" boat has less drag with the stubs than without.

In regard to the critical speed of a solitary wave in a canal, Scott-Russell's early discussion shows that the speed approaches $\sqrt{gh}$ for trivial amplitudes, but $\sqrt{2gh}$ for a very high wave.

Reply to Discussion

Mr. Coombes: Mr. Hill had answered the question by Mr. Gouge concerning sponsons. But Mr. Gouge seemed to have misunderstood the statements in the paper concerning the lift of the sponsons. The sponsons were, of course, attached to the model in the tank tests, and therefore the lift during the take-off was represented. His own remarks about the lift of the sponsons applied to flying conditions. Assuming that a machine with wing-tip floats and a seaplane with sponsons were to have the same landing speed, the seaplane with sponsons could have a smaller wing area, and therefore smaller wing drag. But it was not for him to say how far one could reduce the wing area. He had not made tests in that connection with the particular design he was considering, and when he stated that under favourable circumstances the seaplane with sponsons would have a lower drag than the seaplane with wing-tip floats, he was basing the statement on tests which were made on rather a small model and in a small tunnel. At the R.A.E. there had not been an opportunity to check the maximum lift given by stubs on a number of models; the lift and drag had merely been measured at the incidence of top speed on a fair sized model.

He was afraid that he and his colleagues had not made investigations of the effect of the component of the propeller thrust on porpoising. In the dynamic models there was no thrust represented. They had not reached the stage of using self-propelled models, and he did not know whether they would; if it were found that accurate answers could be obtained without representing such complicated factors as thrust and slipstream, he supposed they would carry on with simple models. They had not yet come up against a design with a very steeply inclined thrust axis.

Commenting on Major Buchanan's reference to the possible influence of surface tension of the water on take-off, he said that full-scale take-off experiments had been made to find the effect of wind on take-off. From the tests, it would seem that the effect of a calm was not nearly so important on the full scale as it would appear from model tests, and what had been ascribed to the surface tension of flat, oily, calm water could be easily explained by the change of load on the water due to the effect of wind on the wings. He had not yet had definite proof that a seaplane offered an unusually large resistance in calm water.

With regard to seaplanes fitted with sponsons becoming laterally unstable, Mr. Coombes pointed out that in a tank one could not carry out sponson tests under every condition. He regretted that he had not been able to show the meeting a film which had been prepared, illustrating the model tests, because the film illustrated the testing of a dynamic model complete with sponsons, in waves, and it indicated the very severe treatment to which they were subjected. If the sponsons were correctly designed, there was no reason why the machine should be unstable laterally whenever a very large overturning moment due to cross wind or other circumstance was produced. Of course, in tank tests one could not allow freedom in yaw, because the model would run into the wall. If a cross wind heeled a seaplane over while it was taxying, the stub would dig in and a big yawing moment would be produced, which would turn the machine out of the wind; that would really be a safeguard, because the centrifugal force acting at the c.g. would oppose the roll. It would be disconcerting for a pilot when a machine was suddenly swung off its course; but that would occur only at low speeds, because at high speeds the restoring moment due to the sponsons would rapidly increase. There was little likelihood of a seaplane being unstable at a speed above 15 knots.

Dealing with the references to tests made in other tanks, he said that a comparative test was being made in the Ottawa tank at the moment, but so far no arrangements had been made for conducting comparative tests in the larger

tanks such as that at Hamburg or that of the N.A.C.A. Of course, one would very much appreciate such comparative tests; but the comparisons being made with full scale at Felixstowe were without doubt even more useful than comparative tank tests. If one could obtain correction factors so that full-scale results could be predicted accurately from tank tests, it did not really matter whether or not the results agreed with those obtained in other tanks. At the same time, he agreed that the value of comparative tank tests was very great.

The remarks made by Mr. Garner concerning the accuracy of measurement at high speeds were quite true. Measurements were very difficult at high speeds, but it was the experience at the R.A.E. that repetition tests did give a mean rather more accurate than would be imagined from the results of a single set of observations. Perhaps Mr. Garner's point about scale effect, and so forth, at high speed had been answered by Mr. Perring, when he had referred to prediction from other laws than Froude's, *i.e.*, from ordinary aerofoil laws. Tests at the lower speeds could be made with comparative ease; by extrapolating up to a higher speed by the use of non-dimensional coefficients, and taking into account the change in Reynolds' number, one might predict fairly accurately the forces on a hull at high speed.

The top speed of the flying boat, the speed of which was reduced by $2\frac{1}{2}$ m.p.h. by the fitting of stubs, was about 150 m.p.h.; and the floats and stubs were comparable. Actually, the floats gave a greater restoring moment than the stubs. It was a general characteristic of stubs that unless one made them prohibitively large one could not get a restoring moment comparable with that of floats of the size at present specified on British flying boats. But floats of good streamline shape and slightly smaller frontal area, reduced to a size comparable with the size of the stubs, would make very little difference to the comparison given.

Mr. Coombes agreed with Mr. Wimperis that, so far as we were aware, dynamic model tests were first made in this country, and there had been no published work on the use of dynamic models in other countries. It was certain that the use of dynamic models was contemplated abroad, however, because the new Italian tank had a specially designed towing carriage, placed on one side and having an arm projected over the middle of the tank, so that there was practically no interference between the carriage and the dynamic model. One disadvantage of the American tests was that the model was fixed by means of a very strong spring, and no indications of behaviour were given.

As to the presentation of results, so long as one assumed no scale effect in the tests, it did not really matter very much whether one plotted the actual model forces and speeds of the full-scale figures; there was merely an arithmetical transformation between them. It might prove much more satisfactory to plot non-dimensional coefficients, as Mr. Perring suggested, and especially, of course, for systematic model tests, *i.e.*, the type of work which the Americans seemed to have been doing quite a lot. A true non-dimensional presentation, such as that in use for the results of aerofoil tests, would possibly solve the problem much better. The R.A.E. plotted the full-scale figures for convenience. He believed that designers, in development tests, much preferred to have the full-scale values plotted; but for the types of test such as those of wall interference and depth effect, he quite agreed that the model forces would have been preferable.

Commenting upon the remarks made by Mr. Perring to the effect that, according to the latest information, the results of dynamic model tests were only very slightly pessimistic, Mr. Coombes said that the whole technique of dynamic model testing, of course, depended on experience; one had to interpret the observations made on a model in order to predict the performance full scale. The models were treated, perhaps, rather roughly; they were disturbed far more violently than the full-scale machines would be disturbed.

Dealing with Mr. Lower's remarks concerning oscillations, he agreed that if a model were oscillated very violently the suspension wires would tend to become slack; one advantage of the air pistons used in the apparatus at the R.A.E. was that they reduced the oscillation to a small amplitude. Whereas one could say that a model was likely to be unstable because it oscillated against the damping of the pistons, on the other hand the oscillations were reduced to a small value, whereby a reasonable resistance record could be obtained. If a model were allowed to porpoise freely, it would perhaps leap off the water, in which event it would be quite impossible to obtain any resistance record whatever.

With regard to wall interference, it was quite true that an image method was not so good as the real wall. The tangential components of the velocity

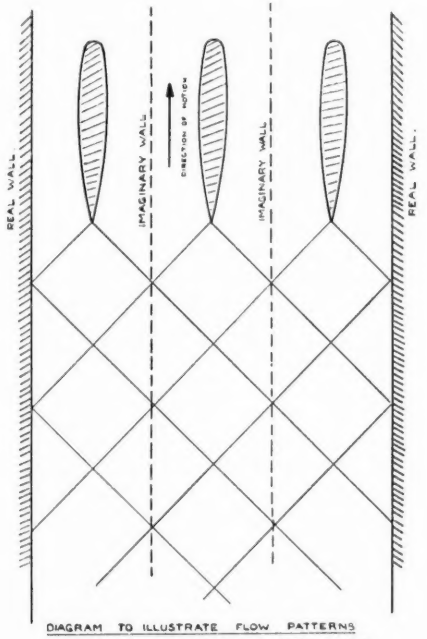

DIAGRAM TO ILLUSTRATE FLOW PATTERNS DURING WALL INTERFERENCE TESTS USING TRIPLE MODELS

were not represented, but they should be very small, and the motion below the water surface, if the models were absolutely identical, should really be more satisfactory than the spray above the surface, which was visible. For the immersed half of the model the effect was the same as in a wind tunnel interference image method. The spray could not ever be made identical on two models, because the very smallest difference would cause one drop of spray to miss its fellow, so to speak.

He had not much experience of twin float interference. Interference had been measured with the triple model hulls, but tests had been made also on a twin float design, having fairly large scale floats, which happened to be available. In that case there was extraordinary agreement between the results of one of the floats tested alone, the two floats towed as a unit, and then one float placed at the centre of the tank and the other alongside it, for interference. But, of

course, interference might be favourable just as it might be unfavourable. It was his experience that there was very little interference between floats.

In a final comment with regard to the kind remarks made concerning the work carried out at the tank, Mr. Coombes emphasised that it could not have been done without the co-operation of all concerned. It was not the work of one person, but the work of a team, which had made the results possible.

(*Communicated.*)—In reply to Professor Ober's enquiry, the pressures in the pistons are adjusted to apply a lift varying as the square of the speed and with attitude. Compressed air is supplied from a container carried on the carriage and recharged four or five times a day between runs. The apparatus is described in some detail in R. and M. 1649.

With regard to Prof. Ober's second point, the interference between the outer pair of models produces the same effect as the reflected flow from a single model between walls. This is clear from the attached sketch on previous page. The method, apart from tangential velocity components at the walls, appears to be exact. The triple models produce an infinite series of images spaced the same distance apart as the models, and an exactly similar series is produced by a single model between walls.

In the paper, there was not sufficient time to discuss the wave amplitudes and speeds observed in the tank, but in R. and M. 1649 will be found a section dealing with this subject. The maximum speed of wave translation observed in the depth effect tests was $1.2\sqrt{gh}$.

(*Communicated.*)—M. M. Stern, of Paris, has sent me a very interesting description of his work with mathematical hull forms. Unfortunately, he has used cross-sections with double curvature. This type of section is uncommon on British seaplanes, and no data for calculating the forces on such planing bottoms are available. Tests of simple planing surfaces with plain and hollow vee sections have been made and the results could be applied to mathematical forms having such sections.

The subject is well worthy of attention, as the effects of such characteristics as beam, angle of vee, etc., can be more easily analysed when the hull lines are mathematical functions of these parameters. If M. Stern would produce a mathematical form with straight or hollow vee sections, it would be of great interest.

ABSTRACTS AND NOTICES

FROM THE

SCIENTIFIC AND TECHNICAL PRESS

Issued by the

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(*Prepared by R.T.P.*)

No. 34. JUNE, 1935

Aircraft Design, etc.

High Performance Flying Boat. (Aviation, Vol. 33, No. 8, August, 1934, pp. 246-249.) (5.10/29751 U.S.A.)

A descriptive technical account is given of the construction of the Pan American four-engine S.42 and illustrated by four photographs.

The performance is given as 182 m.p.h. with 4×650 h.p. for 38,000lb. flying weight, climb 850ft. per minute, 15,500ft. in 47 minutes (world's record).

Aerodynamical Effect of Filleting Wings and Body. (H. Muttray, L.F.F., Vol. 11, No. 5, 25/10/34, pp. 131-139.) (5.11/29752 Germany.)

Eleven photographs show the general appearance and some details of four types of glider with filleting between wings and body. Seven polar diagrams show numerous test points on the polar and moment characteristics of wings only, and of complete models. In one case high wing and low wing characteristics are shown.

The low wing characteristic is less affected by the pilot's wind screen, etc., than the high decker. Filleting brings the polar of the whole machine almost up to that of the wings alone.

Nine references.

Mutual Influence of Wings and External Fittings on the Pressure Side. (H. Muss, L.F.F., Vol. 11, No. 4, 1/10/34, pp. 103-116.) (5.11/29753 Germany.)

The disturbance set up by a low drag body in the flow along the pressure side of a wing can be calculated numerically to a satisfactory approximation by compounding the circulation field with the flow field of the body alone. The reaction of the wing on the airflow round the body can be taken into account. Experimental methods are described and illustrated in considerable detail; in particular, a photograph of a battery of 29 manometers shows the method of observing pressure distribution.

A summary is given of the elementary theory of Joukowsky's simple conformal transformation and of Geckeler's extension to more complicated cases. Numerical examples of building up disturbance fields are shown graphically for cylinders and surface of revolution, with applications to struts and steel fairings.

In general, close similarity in the run of the experimental and calculated curves is obtained, with useful numerical agreements apart from some discrepancies.

Seven references.

British Commercial Aviation in 1934. (Flight, Vol. 27, No. 1359, 10/1/35, pp. 33-36.) (5.14/29754 Great Britain.)

A brief summary is given of internal and Empire routes operated, with two maps.

Airways of Alaska—Report of Progress by Pan American Airways. (Aviation, Vol. 33, No. 8, August, 1934, pp. 240-241.) (5.14/29755 U.S.A.)

The development of airways in replacement of and competition or co-operation with government steamer services and dog team routes, offer special problems. Arctic weather conditions impose additional equipment and precautions.

The equipment of the maintenance and repair base at Fairbanks is described. The weather service is considered inadequate.

World Airways, 1934. (D. Sayre, Aviation, Vol. 33, No. 8, August, 1934, pp. 235-239.) (5.14/29756 U.S.A.)

A review of development is given with statistics of Pan American, Imperial Airways, Royal Dutch, Deutsche Luft Hansa, and Air France operations.

Competition, pooling agreements and subsidies are discussed.

Flying Boats and Their Possible Developments. (A. Gouge, Flight, Vol. 27, No. 1368, 14/3/35, pp. 282-283 and 288.) (5.154/29757 Great Britain.)

Lengthy extracts are given from a paper read at the North East Coast Institution of Shipbuilders and Engineers.

Rules are given for hull design in relation to impact on water at five angles. Reference is made to the usual devices for increasing size without ignoring the fundamental physical difficulty that masses of similar structures increase as the cube, and cross sections as the square of linear dimensions.

A design is outlined for a flying boat with a total flying weight of 300,000lb., on the basis of curves extrapolated from the author's experience. The power required would be 24,000 b.h.p.

Measurement of Amplitude and Frequency of Vibration on Aircraft. (R. Papault, L'Aéron., No. 184, September, 1934, p. 81.) (5.17/29758 France.)

A light coil carrying continuous current is attached to the vibratory part, and the amplitude and frequency of vibration are determined from the current induced in a fixed coil. An electrical amplifying valve circuit is described, with response practically independent of the frequency.

An oscillation of 17 mm. amplitude and 15 cycles per sec. frequency produced a current varying between 45 and 110 milliamperes, as the mean distance between the coils was varied from 12 to 3 cm.

Vibration Response of Aeroplane Structures. (T. Theodorsen and A. G. Gellalles, N.A.C.A. Report No. 491, 1934.) (5.17/29759 U.S.A.)

From Authors' Abstract.—This report gives test results of experiments on the vibration-response characteristics of aeroplane structures on the ground and in flight.

In the ground tests a study was made of the vibration-response of the fuselage, wings and tail by applying sinusoidal forces and couples at different

parts of the fuselages of two aeroplanes. The amplitudes of vibration along the fuselage and wings at various frequencies were measured and plotted, and the important natural modes of vibration were determined.

In the flight tests vibration records were taken in the cockpits and the tails of two aeroplanes. The vibrograms obtained in flight tests were analysed and the amplitudes of the fundamental frequencies and the most important harmonics were plotted.

Six references.

Drag of Tapered Cantilever. (R. H. Upson and M. J. Thompson, J. Aer. Sci., Vol. 1, No. 4, October, 1934, pp. 168-177.) (5.20/29760 U.S.A.)

Empirical expressions for so-called profile drag are taken from a mass of test data, while the induced drag is amenable to mathematical analysis. The semi-empirical expressions are integrated along the span of tapered wings and somewhat formidable expressions are obtained.

Numerical values are given in tables and graphs. A taper of 8 : 1 from root to tip appears to give the best combination for low structural weight and low drag, with reservations as to the effect on aileron control and losses at the junction of wing and body.

Eleven references.

Effects of Cut-out on Wing Characteristics. (T. Okamoto, Aer. Res. Inst., Tokyo, Report No. 113 (Vol. 9, No. 5), October, 1934.) (5.20/29761 Japan.)

Three profiles with cut-outs of increasing length along the span and constant depth along the chord were compared with the original wing and a wing with shortened chord along the whole span.

Seven profiles with cut-outs of constant length along the span and increasing depth along the chord were compared with the original wing. A special model had portions cut out, both from leading and trailing edges.

Five Göttingen profiles and a Sloane modified profile were used.

A mass of test results is given graphically in 55 diagrams.

Tests of 16 Related Aerofoils at High Speeds. (J. Stack and A. E. v. Doenhoff, N.A.C.A. Report No. 492, 1934.) (5.20/29762 U.S.A.)

From Author's Abstract.—The tests were conducted at low incidences for speeds extending from 35 per cent. of that of sound to slightly in excess of the speed at which a breakdown of flow occurs. The corresponding Reynolds number range is 350,000 to 750,000.

The results obtained were applied to the design of three cambered aerofoils, which were tested as part of this investigation.

The results indicate that some further improvement in aerofoil shapes for high-speed applications may be expected.

Five references.

Model Measurements to Find Best Form of Cockpit Cut-outs in Open Sector Aeroplanes. (Luftfahrtforschung, Vol. 11, No. 3, 18/8/34, pp. 85-92.) (5.40/29763 Germany.)

Experimental information was sought on the form of cut-out giving the observer maximum protection from wind with minimum additional drag. The resistance coefficient was determined over the usual range of incidence, and the flow round the cockpit was studied by observing streamers. Stepped shields on a normal body produced an increase of drag corresponding to a mean resistance coefficient of about 0.2 over the surface of the step.

Aircraft, Landing Gear

Drag of Aeroplane Wheels, Wheel Fairings and Landing Gears. (W. H. Herrnstein and D. Biermann, N.A.C.A. Report No. 485, 1934.) (5.50/29764 U.S.A.)

From Authors' Abstract.—Tests were made in the 7 × 10ft. wind tunnel and in the 20ft. tunnel. The results of the investigation show that the lowest drag recorded for any landing gear tested was 13lb., at 100 m.p.h. and 0° pitch, and that it might be possible to reduce this drag approximately 6lb. by totally encasing the wheels of this gear in fairings. The highest landing gear drag recorded was 98lb.

Eight references.

Modern Wheel Brakes. (Flight, Vol. 27, No. 1358, 3/1/35, pp. 4-7.) (5.58/29765 Great Britain.)

A survey is given of types in use—Bendix, Palmer, Dunlop and Vickers, with details of cable, pneumatic and hydraulic control. Diagrammatic arrangements are shown in five sketches.

Airscrews and Marine Screws

Steering of Ships. (K. Schaffran, W.R.H., Vol. 15, No. 16, 15/8/34, pp. 215-216.) (5.60/29766 Germany.)

Photographs show a right-handed model screw in a test tank with a rudder split horizontally on the line of the axis with two sections and with a rudder split into twelve parallel sections. In the former case the upper and lower halves are diverted right and left by the wake; in the latter the strips form a spiral surface and give an indication of the general direction of the spiral flow at different axial distances.

Three references.

Systematic Tests of Water Screw Models. (K. Schaffran, W.R.H., Vol. 15, No. 22, 15/11/34, pp. 324-327.) (5.612/29767 Germany.)

Twenty-five two-blade, 25 three-blade and 20 four-blade model water screws are shown with stepped increases of pitch and width. The dimensions are specified and two typical sets of blade sections along the blade are shown in sketches.

Four diagrams are drawn showing families of characteristic curves of efficiency thrust, torque and slip.

Elementary formulæ are given and two numerical examples are worked out.

Three references.

Variable Pitch Airscrew. (R. A. Capon (letter), Engineering, Vol. 139, No. 3611, 29/3/35, p. 345). (5.64/29768 Great Britain.)

The utility of variable pitch airscrews depends on the aeroplane speed and speed range. In the past variable pitch was rarely worth the complication, at present it is useful in some cases; in future it may become indispensable.

Variable Pitch Propellers. (F. Gutsche, Z.V.D.I., Vol. 78, No. 37, 15/9/34, pp. 1073-1081.) (5.64/29769 Germany.)

The advantages of variable pitch for water and airscrews are discussed. Marine screws of variable pitch have so far received little application on account of possible damage by impact.

Successful variable pitch airscrews have been developed in America and France. Variation of pitch by elastic deformation of the propeller has led to

excessive loss of efficiency. The concomitant reduction of noise is of value in civil and military aircraft. The problem of decelerating fighting aircraft after a dive has received consideration in America.

Twelve references.

Constant Speed Propeller. (Aero Digest, Vol. 25, No. 6, December, 1934, p. 49.) (5.64/29770 U.S.A.)

A Hamilton firm has designed a governing device (operated by the machine gun synchronising gear) which keeps their variable airscrew at constant r.p.m.

Reduction of Aerodynamic Resistance by Guide Surfaces. (K. Frey, Z.V.D.I., Vol. 78, No. 33, 18/8/34, p. 290.) (5.644/29771 Germany.)

This is an abstract of more extensive work in Forschung, Vol. 4, 1933, p. 67, and Vol. 5, 1934, p. 105.

Guide surfaces suitably arranged in lattice round a blunt body may reduce the eddy resistance by over 80 per cent. Similar results are obtained in channels with a sharp bend or a sudden increase in cross-section.

Three references.

Venturi Cowling for Water Screws. (E. K. Rosscher, W.R.H., Vol. 15, No. 22, 15/11/34, pp. 328-330.) (5.644/29772 Germany.)

Photographs show a model and full-scale water screw with venturi cowling installed in a tug steamer. Diagrams illustrate Froude's momentum theory and show approximately the ideal streamlines.

Dimensions are given in a table, and figures of performance are shown graphically. Substantial improvement in performance is claimed.

Twin-Cowled Water Screws. (Landsberg, W.R.H., Vol. 15, No. 19, 1/10/34, pp. 268-270.) (5.644/29773 Germany.)

Photographs show three views of a 55 h.p. Diesel-engined tug fitted with screws running in cowls. The hydrodynamical boundary conditions resemble closely the aerodynamical conditions in the " Stipa " aeroplane.

The load was supplied by towing three passenger vessels lashed side by side, two headed in the reverse direction, and varying the load by working their screws against the direction of tow. Test results are shown in tables and curves.

The standstill pull was 2.3 tons and the maximum overall towing efficiency 50 per cent. at 9 km. per hour and 9/10ths ton pull.

Instruments

An Instrument for Drawing Evolute Curves. (H. Hofer, Z.V.D.I., Vol. 78, No. 40, 6/10/34, p. 1170.) (6.0/29774 Germany.)

A simple drawing instrument is described, by the use of which a fairing of evolute curves can be traced graphically. It can be applied to the design of gear wheels and to the solution of certain transcendental equations. The quadrature of the circle is given as an example.

Impulse Counter for Rapid Impulses. (H. Alfven and P. Ohlin, Z.V.D.I., Vol. 78, No. 46, 17/11/34, p. 1342.) (6.0/29775 Germany.)

The ordinary mechanical relay fails to respond to impulses beyond a moderate frequency. An electric circuit using ordinary valves is described, which transmits only every tenth impulse to the counter.

Two references.

Water Flow Measurements in Inclined Channels. (Z.V.D.I., Vol. 78, No. 33, 18/8/34, p. 987.) (6.22/29776 Germany.)

The direction of flow across a section is estimated from the attitude taken up by light vanes which are freely pivoted. The position of equilibrium and the velocity along the vane are recorded. Surface integration over the cross section gives the total flow.

Two references.

Measurement of Water Flow at a Hydro-Electric Power Station. (J. M. Mousson, Z.V.D.I., Vol. 78, No. 46, 17/11/34, pp. 1343-1346.) (6.22/29777 Germany.)

A 42,000 h.p. Kaplan turbine is installed at Safe Harbour, U.S.A., with a total flow of about 250 m.^{3}/sec. The flow was integrated over a section of the turbine intake from readings of 84 calibrated vane meters of German design. The estimated accuracy is within $\pm\frac{1}{4}$ per cent. and agrees with the Gibson method within a fraction of 1 per cent.

Eleven references.

The Relation Between Translatory and Rotary Viscosity. (J. L. Snoek, Phys. Zeit., Vol. 35, No. 22, 15/11/34, pp. 911-914.) (6.225/29778 Germany.)

The coefficient of viscosity of solutions of substances with asymmetrical or polar molecular constitutions in the apolar solvents $C\text{-}Co_4$ and C_6H_6 was determined experimentally and fundamental relations of the kinetic theory were verified.

Nine references.

A New Electrical Indicator for High Speed Combustion Engines (Siemens). (C. W. Fieber, Autom. Tech. Zeit., Vol. 37, No. 20, 25/10/34, pp. 523-528.) (6.252/29779 Germany.)

Deformation of the pressure diaphragm produces changes in electrical capacity. In calibrating the relation between condenser current and pressure, temperature effects must be taken into account.

Characteristic curves recorded by a Siemens oscillograph are reproduced.

Fifteen references.

Frequency Limits of Belt Drive for Torsiograph. (J. Geiger, Autom. Tech. Zeit., Vol. 37, No. 17, 10/9/34, pp. 453-454.) (6.271/29780 Germany.)

The 50 mm. standard cotton belt (length 170 mm.) is satisfactory up to frequencies of 3,500. By waxing the belt the frequency may be increased to 6,000, with a small correction for slip. At higher frequencies a direct drive is desirable.

Measurement of Marine Screw Thrust. (H. E. Saunders, Engineering, Vol. 139, No. 3599, 4/1/35, pp. 25-26.) (6.272/29781 Great Britain.)

A comprehensive survey is made of the literature on the subject and the devices used.

The precautions to be taken in obtaining and interpreting the results are discussed.

Gearing in Watches and Instruments. (H. Grenda, Z.V.D.I., Vol. 78, No. 40, 6/10/34, p. 1174.) (6.3/29782 Germany.)

Evolute gearing possesses great advantages and should replace cycloidal gearing as suitable tools become generally available.

Italian Electro Cinema for Timing Aircraft. (L'Aéron., No. 184, September, 1934, pp. 214-217.) (6.3/29783 France.)

Two synchronised electric chronometers are used in conjunction with two high speed double objective cinema cameras placed at the ends of a 3 km. base. Exposures are made at the rate of 100 per second. The instant at which the aircraft crosses the line at each extremity of the base can be determined to 1/500 second by reduction of the cinema and chronometer records.

Flight Path Recorder "Quo Vadis" Made by Zeiss. (Luftwissen, Vol. 1, No. 8, August, 1934, pp. 230-231.) (6.51/29784 Germany.)

In aerial topography it is essential that the surveying aircraft should maintain a steady flying path. An instrument installation is described which comprises ground speed, drift, height and direction indicators, and a mapholder with recording pen and driving motor. A camera obscura exhibits the downward field of view and a pointer is geared to travel across the field with the same speed and direction as the landscape.

One reference.

A New Surface Extensometer. (T. W. K. Clarke, J. Sci. Inst., Vol. 12, No. 3, March, 1935, pp. 84-91.) (6.56/29785 Great Britain.)

Two plane mirrors, mutually at right angles, are mounted on a test piece so that increase of the test length deflects one of the mirrors. A beam from the focus of a lens, incident on one of the mirrors and reflected from the other, gives a linear displacement in the field, which is proportional to the angular deflection and to the extension.

Methods of meeting the mechanical difficulties of construction and manipulation are discussed. Measurements of extension could be made to half a millionth inch, corresponding to 1/500 of the average maximum strain for steel on the test length of 0.2 inches.

Results of Measurements of Accelerations in Aircraft Due to Gusts. (R. Maletzke, Luftwissen, Vol. 1, No. 10, 15/10/34, pp. 279-283.) (6.73/29786 Germany.)

The gustiness of the air was estimated from the vertical acceleration of the aircraft recorded on a special instrument. The distribution of gusts near the ground was found to depend largely on the configuration of the land. At high altitude the proximity of clouds exerted an influence, which became marked during thunderstorms.

The data obtained are essential for glider pilots and are valuable to the pilots of passenger craft in determining the best altitude and path for smooth conditions, according to the time of day, the prevailing wind and the cloud formations.

Acoustical Instruments. (A. B. Wood, J. Sci. Inst., Vol. 12, No. 2, February, 1935, pp. 49-50.) (6.96/29787 Great Britain.)

A brief description is given of various noise meters and accessories on the market.

Aircraft Flight

Siemens Autopilot. (Flight, Vol. 27, No. 1359, 10/1/35, pp. 41-42.) (7.50/29788 Great Britain.)

A description is given, with four photographs of details and a diagram of connections and controls.

The installation includes course indicator, course setter, rate of turn selector, speed selector, pitot tube, pendulum, tele-compass, gyroscopes, electric generator and oil pump.

A New Automatic Pilot. (Flight, Vol. 27, No. 1368, 14/3/35, pp. 287-288.) (7.50/29789 Great Britain.)

A description is given of the Pollock Brown automatic control, with details of the special gyro mounting and transmission to the servo controls.

Photographs show the general arrangement and some details. A diagram shows the mechanical connections of the servo control.

Servo-Control Flaps. (E. G. Reid, J. Aer. Sci., Vol. 1, No. 4, October, 1934, pp. 155-167.) (7.54/29790 U.S.A.)

A statement is given of the elementary hydro-mechanical principles of the Flettner rudder and of derived types of flap, applied to aeroplane rudders. In general, the control moment required for the main rudder is much reduced.

General arrangements are shown in photographs and sketches. Measured moments about hinge or rudder post are shown graphically for different areas, shapes and relative angular settings of the flaps.

Eight references.

Theory of Servo-Mechanisms. (H. L. Hazen, J. Frank. Inst., Vol. 218, No. 3, September, 1934, pp. 279-331.) (7.54/29791 U.S.A.)

Coupled systems are shown diagrammatically in which a relative motion of controller shaft from a mean position sets in action a relay, which in turn applies a restoring moment.

The friction and inertia of the intervening mechanism, the relation of torque to angular displacement, etc., enter into the functional relations between time and control movement and torque.

Equations are formed for three types of control. A diagram of response is drawn for continuous control servo-gear.

Thirty-two references.

Design and Test of High Performance Servo-Mechanism. (H. L. Hazen, J. Frank. Inst., Vol. 218, No. 5, November, 1934, pp. 543-580.) (7.54/29792 U.S.A.)

Application of the theory of the previous article (see Abstract 29791) is made to servo-control, in which a d.c. vacuum tube amplifier feeds a small d.c. motor of low inertia, with high damping, which in turn drives a (mechanical) torque amplifier.

The mathematical theory is developed and details of design are given in sketches and a photograph.

With critical dead-beat damping the transient current following sudden applications of constant input lasted about 1/10 seconds.

Four references.

The Junkers Double Wing. (H. E. Billeb, Aeroplane, Vol. 48, No. 1241, 6/3/35, pp. 269-271, and Luftwissen, Vol. 2, No. 1, January, 1935, pp. 2-5.) (7.72/29793 Great Britain.)

A lengthy summary is given of the article in Luftwissen for January, 1935.

A small auxiliary wing is set in tandem, but slightly below the main wing. The experimental values of pressure distribution, lift, drag and moment coefficients are given graphically. Full-scale test figures are also given. The most notable point is the large increase in lift obtained by setting of the auxiliary wing at an angle with the main wing.

Methods of employing the double wing in practical design are described. It has found application in a series of successful commercial aircraft.

Effects of Full-Span and Partial-Span Split Flaps on the Aerodynamic Characteristics of a Tapered Wing. (C. J. Wenzinger, N.A.C.A. Tech. Note No. 505, September, 1934.) (7.72/29794 U.S.A.)

From Author's Abstract.—Aerodynamic force tests were made in the N.A.C.A. 7 × 10ft. wind channel on a highly tapered Clark Y wing equipped with various split flaps.

The investigation showed that with full-span split flaps the lift and drag characteristics of the tapered wing up to the stall are similar to those of a rectangular wing with flaps of comparable size, but that the stall of the tapered wing with full-span flaps occurs at progressively lower angles of attack with increasing flap deflection up to that for maximum lift. For partial-span tapered split flaps on a tapered wing the maximum lift and the drag at maximum lift is greater, and the lift-drag ratio at maximum lift is less, when the partial-span flap is located at the centre of the wing than when it is located at the tip portion.

Four references.

Calculated Effect of Trailing-Edge Flaps on the Take-off of Flying Boats. (J. B. Parkinson and J. W. Bell, N.A.C.A. Tech. Note No. 510, November, 1934.) (7.72/29795 U.S.A.)

From Authors' Abstract.—The results of take-off calculations are given for an application of simple trailing edge flaps to two hypothetical flying boats, one having medium wing and power loadings and consequently considerable excess of thrust over total resistance during the take-off run, the other having high wing and power loadings and a very low excess thrust.

Five references.

Effects of Equal-Pressure Fixed Slots on the Characteristics of a Clark Y Aerofoil. (A. Sherman and T. A. Harris, N.A.C.A. Tech. Note No. 507, October, 1934.) (7.72/29796 U.S.A.)

From Authors' Abstract.—A type of fixed open slot so arranged that no flow would pass through it at a lift coefficient corresponding to high-speed flight was investigated in the N.A.C.A. 7 × 10ft. wind tunnel to determine the possibilities of such a high-lift device for increasing the speed-range ratio of a wing.

The results of this investigation show that the condition of no air flow through the slot at the desired lift coefficient is attainable. The surface discontinuities produced by the slot openings have, however, such a large effect on the drag that such slots show little promise. An appreciable increase is produced in the maximum lift and the speed-range ratio can be as high as for the plain wing.

Six references.

Engines, Thermodynamics

New Researches on the Ignition Delay in Compression Ignition Engines. (A. E. Thiemann, Autom. Tech. Zeit., Vol. 37, No. 23, 10/12/34, pp. 600-603.) (8.13/29798 Germany.)

A useful summary is given of American research. A short ignition delay is important in high speed operation, and is most readily obtained by a combination of high compression ratio and supercharge. Unfortunately this leads to high explosive pressures, to withstand which special bearing materials are required.

Seven references.

Temperature and Latent Energy in Flame Gases. (B. Lewis and G. von Elbe, Engineer, Vol. 159, No. 4129, 1/3/35, pp. 230-231.) (8.13/29800 Great Britain.)

In contradiction with W. T. David, the authors find that the observed flame temperatures of mixtures of air and H_2 or CH_4 approach within a few degrees

the calculated adiabatic temperatures (of the order of 2,000°), while even for CO the discrepancy of 97 degrees represents only 5 per cent. of the energy in contrast with David's estimate of 20 per cent.

The sodium line reversal method is considered to be fully confirmed. The evidence is discussed and a reply by Professor David follows.

Twenty-five references.

Ignition and Combustion in the Direct Injection Engine. (W. Wentzel, Forschungsheft, No. 366, May/June, 1934, pp. 14-26.) (8.13/29799 Germany.)

The fuel is injected into the products of combustion of a previous explosion of H_2 or C_2H_2. The proportion of these gases is such that the charge, heated and compressed by the explosion, contains 20 per cent. O_2 and thus resembles atmospheric air.

Lag in the ignition of a specified fuel is mainly governed by temperature and little affected by density. The time of combustion is not affected by air temperature, provided the latter exceeds the ignition temperature by a sufficient margin. The results are in general agreement with available engine tests.

Thirty-one references.

Combustion Chart and the Formation of Soot. (G. Ackermann, Forschungsheft, No. 366, May/June, 1934, pp. 1-5.) (29801 Germany.)

In the injection engine incomplete combustion is accompanied by the formation of soot, although there is practically no CO in the exhaust. Charts are given for estimating the heat wasted from the CO_2 and O_2 content of the exhaust of a fuel of known composition.

Eight references.

Precision Optical Pyrometer. (M. Milford, R. J. Bracey, F. A. Cunnold and A. C. Egerton, J. Sci. Inst., Vol. 12, No. 3, March, 1935, pp. 80-84.) (8.14/29802 Great Britain.)

A platinum filament in a standard glass bulb is brought into optical coincidence with the observed hot body and heated by electric current until it matches. The current is measured to 0.01 per cent., corresponding to temperature difference of 1/3°C. at the m.p. of gold (1,063°C.).

Details are given of the optical system monochromatic colour filters, absorption screens, etc. Temperatures up to 5,000°K. were measured with the use of absorption screens.

Engines, Design and Performance

Development of Aero Engine Design—Notes on the Paris Salon. (Luftwissen, Vol. 1, No. 12, 15/12/34, pp. 339-344.) (8.20/29803 Germany.)

A tabular list of engines is given.

Much progress has been made in large air-cooled engines (both radial and in line). Moderate supercharge (10,000 feet) is becoming general for medium and large sizes. The variable pitch airscrew is still in the experimental stage.

The "Rapier" Aero Engines. (Flight, Vol. 27, No. 1368, 14/3/35, pp. 266-269.) (8.20/29804 Great Britain.)

A descriptive account of the "Rapier" II and IV is given, with photographs and perspective drawings showing general arrangements and details. A specification gives principal dimensions and performance.

Design and Construction of High Speed Two-Stroke Engines. (H. J. Venediger, Autom. Tech. Zeit., Vol. 37, No. 19, 10/10/34, pp. 495-502, and No. 20, 25/10/34, pp. 529-535.) (8.21/29805 Germany.)

Numerous two-stroke multi-cylinder installations are described, with scavenging by the crankcase or by an independent system of reciprocating or rotary blowers. The author is of the opinion that the crankcase compression engine 1-3 cylinders, not exceeding one litre total stroke volume, is ideal for small cars.

Suitable blowers are not yet available.

Ten references.

Ignition and Combustion in the Diesel Engine. (G. D. Boerlage and J. J. Broeze, Forschungsheft, No. 366, May/June, 1934, pp. 6-13.) (8.273/29806 Germany.)

In accordance with the old views of Rieppel on the importance of vapourisation and cracking, ignitability in the injection engine is determined by the tendency of a fuel to break up rather than by its affinity for oxygen.

Development of the injection engine is largely a question of mechanical design which affects profoundly the fuel mixture distribution in the cylinder and influences ignition lag. The use of dopes to reduce ignition lag does not increase the thermal efficiency as in the carburettor engine.

Nineteen references.

Engine Installation in Tankers. (E. Goos, Z.V.D.I., Vol. 78, No. 47, 24/11/34, pp. 1361-1367.) (8.275/29807 Germany.)

Supercharging of the eight-cylinder single acting four-stroke Diesel engine (airless injection) is effected by the underside of the power piston, the piston rod passing through a stuffing box. The brake mean effective pressure is raised to 115lb. per sq. in., with a consumption of less than 0.4lb. per b.h.p. per hr.

Mobile Electric Starting Battery—for Aero Engines. (Luftwissen, Vol. 1, No. 8, 15/8/34, p. 229.) (8.284/29808 Germany.)

Batteries in trucks are used on the flying ground for starting aero engines, with electrical self-starters. The available ampere-minutes are increased indefinitely and the battery installed in the aircraft is relieved of its heaviest duty.

Introduction of Fuels in the Carbon Dust Engine. (K. Zinner, Z.V.D.I., Vol. 78, No. 34, 25/8/34, pp. 1007-1010.) (8.290/29809 Germany.)

The carbon dust engine of Pawlikowski has been modified by adding an auxiliary chamber into which the dust is introduced during the induction stroke. The chamber communicates permanently with the combustion chamber of the engine. Transfer of the dust is, however, prevented by air currents till the piston has started the working stroke.

The author investigates the principle of this injection by means of a model, in which combustion does not take place. The dust is not stored under pressure, but is picked up by auxiliary air in a sort of carburettor and transferred to the auxiliary chamber through a normal valve operating late in the induction stroke. From the experiment it appears possible to adopt this principle on a full-scale engine.

Four references.

High Speed Gas Engine. (F. Hegenmuller, Z.V.D.I., Vol. 78, No. 47, 24/11/34, p. 1380.) (8.293/29810 Germany.)

Small gas engines, with four or six cylinders, rated up to 60 h.p. and operating at speeds in the neighbourhood of 1,250 r.p.m. are successfully competing with Diesel engines, where cheap power gas is available.

Steam Propulsion for Aircraft. (Z.V.D.I., Vol. 78, No. 50, 15/12/34, p. 1456.) (8.294/29811 Germany.)

American experiments and designs are discussed. Flight tests were carried out with a 90 h.p. two-cylinder engine using steam at 77 atmospheres, total plant weight about 1,000lbs. Projected turbine plants of 1,000 h.p. show estimated weights of 3lb. per h.p.

The efficiency increases up to 30,000 feet and then decreases rapidly. Wing condensers are essential and these present great difficulties. The possibilities of steam power appear to be restricted to large units operating at relatively high altitudes.

Four references.

Hydraulic Similarity in Steam Turbine Construction. (E. Sorensen, Z.V.D.I., Vol. 78, No. 48, 1/12/34, pp. 1403-1410.) (8.294/29812 Germany.)

A special model test plant for speeds up to 12,000 r.p.m. and powers up to 300 h.p. has been installed in the Engineering Laboratory of the Dresden Technical High School. Systematic tests on blade form, leakage, etc., are in progress.

A discussion is given of the condition of dynamical similitude for comparison of full-scale and model experiments. High model speeds are required, and the separation of skin friction and ventilation losses presents difficulties.

Five references.

Engines, Design and Strength of Components

Damping of Torsional Oscillations of Engines. (J. Geiger, Z.V.D.I., Vol. 78, No. 46, 17/11/34, pp. 1353-1355.) (8.36/29813 Germany.)

In the absence of an external damper, torsional oscillations are damped by mechanical and aerodynamical friction and by elastic hysteresis, mainly in the shaft. Quasi-damping is also produced by the detuning effect produced by the reciprocating masses.

With mild resonance the more important damping terms are due to friction, with severe resonance to hysteresis. In an eight-cylinder double acting two-stroke engine the damping due to hysteresis varied between 30 and 60 per cent. of the total, according to the severity of the critical.

For large shear strains hysteresis losses have been found to vary as about the 6.5th power of the strain. The strain varies inversely as the cube of the shaft diameter, hence, for large strains, hysteresis losses vary inversely as about the 20th power (3×6.5) of the shaft diameter and are very sensitive to changes of diameter.

With high amplitudes and stresses the total damping losses may amount to 12 per cent. of the power, with corresponding increase in fuel consumption.

Fourteen references.

Removal of Critical Torsional Periods by Elastic Couplings. (J. Geiger, W.R.H., Vol. 15, No. 23, 1/12/34, pp. 341-343.) (8.36/29814 Germany.)

Elementary considerations are given briefly. The particular case of an elastic coupling with non-linear torsion-couple characteristic is discussed graphically, and numerical results are given, also graphically, in illustration of the more important practical points of the problem.

Bearing Metals for Diesel Engines. (Autom. Tech. Zeit., Vol. 37, No. 18, 25/9/34, pp. 489-490.) (8.37/29815 Germany.)

Thin lead bronze bearings with a steel backing have given good results, provided the backing shell is thin enough to follow the deformation of the crank-

shaft. A radial arrangement of the lead crystals relatively to the backing gives good adhesion.

A Brinell hardness exceeding 30 increases the shaft wear. The life of these bearings is two or three times the life of ordinary white metal bearings, and the smaller amount of material more than compensates for the higher price of lead bronze.

Production of Cracks in Water-Cooled Piston Rods of Diesel Engines. (K. Daeves, E. Kamp and K. Holthaus, Z.V.D.I., Vol. 78, No. 36, 8/9/34, pp. 1065-1067.) (8.38/29816 Germany.)

Failure of piston rods is due to corrosion by the cooling water, concentrated at the position of highest stresses, where the straining of the material causes the cracking and peeling off of the protective oxide film. Positive protection is given by shrinking copper/nickel or chrome/nickel steel tubes inside the hollow piston rod.

Chemical treatment of the cooling water and the addition of oil emulsion reduce the corrosion.

Six references.

Engines, Cooling

Flow of Heat in Laminated Iron Cores. (H. Bucholz, Z.A.M.M., Vol. 14, No. 5, October, 1934, pp. 285-294.) (8.40/29817 Germany.)

The equation of heat flow is written down with different coefficients of heat conductivity parallel and perpendicular to the lamination.

The solutions are given in the form of integral equations, and standard methods of reduction are applied.

A numerical example is worked out and exhibited graphically.

Four references.

Formation of Drops. (A. Adler, Phys. Zeit., Vol. 35, No. 21, 1/11/34, pp. 864-867.) (8.40/29819 Germany.)

Fluid was allowed to flow at controlled speeds through a fine tube, 1 mm. dia., with a plane nozzle face. The rate of detachment of drops, under gravity, was observed and plotted as a function of the weight. Three sets of experimental figures are tabulated and curves are drawn.

Four photographs show drops immediately after detachment. A thread of fluid may follow the principal drop and break up into smaller subsidiary drops under surface tension.

Seven references.

Cooling of Finned Cylinders. (A. E. Biermann and B. Pinkel, J. Aer. Sci., Vol. 1, No. 4, October, 1934, pp. 178-185.) (8.40/29818 U.S.A.)

Seventeen dimensioned section sketches show the type of cylinder fins tested in the wind channel.

The total heat radiated per degree per hour is plotted against fin width for a range of air speeds from 80 m.p.h. to 150 m.p.h. The same quantity is plotted against average fin space and against air speed in separate diagrams.

Reference is made to the theory of physical dimensions, and the heat flow equations are developed in semi-empirical form for application to the present problem.

Finally iso-lines of heat transfer are plotted against fin thickness and spacing so that the optimum fin disposition may be selected.

Five references.

The Air Cooling of Motor Car Engines. (W. Kamm and others, Z.V.D.I., Vol. 78, No. 43, 27/10/34, pp. 1253-1256.) (8.420/29820 Germany.)

For continuous operation, the internal temperature of the cylinder wall must not exceed 180°C. The use of alloy pistons limits the crown temperature to about 320°C. and the ring groove temperature to about 290°C. as determined by fusible plugs. Higher wall temperature invariably leads to piston seizures.

In the motor car (as distinct from aircraft) the cooling air must be supplied by a blower. To keep the work of this blower within reasonable limits the cylinders must be enclosed by a cowling designed to equalise the cooling. The best results have been obtained by blowing the air transversely to the (fore and aft) line of cylinders. The air stream enters at one side of the engine, passes between the cylinders and escapes at the other side. This involves a larger cowling and wider spacing of the cylinders.

Air-cooled engines are inherently noisy, by reason of valve clatter and piston clearance necessitated by the relatively wide temperature range. Effective regulation of the blower is difficult for slow running, hill climbing, cruising, etc. Air-cooled engines reach their operating temperature quickly, which is an advantage in cold climates and reduces wear. Air-cooled lorry engines are receiving attention from this point of view.

Seven references.

Engines, Lubricants and Lubrication

Refining Aviation Lubricating Oil. (Aero Digest, Vol. 25, No. 6, December, 1934, p. 49.) (8.50/29821 U.S.A.)

The oil is treated with two solvents which cause separation of the valuable paraffinic constituents from the non-paraffinic and asphaltic materials. The latter are held to be mainly responsible for gumming of rings, sludging, and excessive deposition of carbon. The resulting solutions are easily separated by differences in density. The process, known as "Clearosol," is handled commercially.

Production of Lubricating Oil in Germany. (B. Scheifele, Z.V.D.I., Vol. 78, No. 31, 4/8/34, pp. 932-934.) (8.50/29822 Germany.)

Apart from synthetic oils a selective absorption process, by amyl alcohol, has been applied to extract lubricating oils from distillation residues of German crudes. Synthetic oils, mainly from condensation products of ethylene, have high viscosity and low pour points.

The cultivation of linseed and soya beans for oil production is encouraged.

The Testing of Lubricating Oils by Surface Tension between Oil and Water. (L. Ringuet, Pub. Sci. et Tech., No. 52, 1934.) (8.540/29823 France.)

The surface tension of the oil film is measured by the immersed ring method which detects readily 1/10 per cent. of oleic acid in a paraffinic oil. The artificial ageing of oil can be followed and the surface tension compared with that of used engine oils.

It is shown that the ageing is largely a question of oxidation.

Lubricants for Car and Aircraft Engine. (H. Vogel, Autom. Tech. Zeit., Vol. 37, No. 18, 25/9/34, pp. 474-480.) (8.540/29824 Germany.)

Certain lubricating oils which do not pass British Air Ministry specification tests give satisfactory performance on Continental air lines, which indicates that laboratory oil tests may be inconclusive. In practice the quality of an oil is judged by the time between engine overhauls. This is affected by the composition of the fuel and by the mixture strength.

Results of tests which do not reproduce equivalent conditions may be incapable of correlation with full-scale test results.

Eighteen references.

Lubrication of Gear Boxes. (E. Fraunhofen, Autom. Tech. Zeit., Vol. 37, No. 19, 10/10/34, pp. 503-507.) (8.580/29825 Germany.)

The quality of the oil is judged by the rate of wear and pitting of the teeth under running conditions. Thermally or electrically polymerised oils (called extreme pressure lubricants in U.S.A.) give improved results.

The addition of sulphur and carbon tetrachloride to ordinary lubricating oils improves the quality. It is well known that the addition of stearates or fatty acids to the gearbox oil reduces leakage and noise but does not reduce wear. Reduction of noise is therefore not an indication of improved quality.

Two references.

Oil Cooling Problem in Aircraft Engines. (H. Caminez, J. Aer. Sci., Vol. 1, No. 3, July, 1934, pp. 131-134.) (8.582/29826 U.S.A.)

The heat dissipated by the lubricating oil increases rapidly with r.p.m. and decreases with rise of oil temperature. It is essential that oils should operate at higher temperature without increased carbonisation and piston ring sticking. Good oils allow of smaller coolers with less air resistance.

Engines, Fuels

The Grading of Motor Oils from Carbon Residue with respect to the Conradson Number. (J. Formanck, Autom. Tech. Zeit., Vol. 37, No. 15, 10/8/34, pp. 398-400.) (8.640/29827 Germany.)

A 50 hrs. test in a four-cylinder water-cooled engine showed that the carbon deposits of a series of oils bore no relation to the Conradson number. The weight of the deposit in the engine depends on adhesion to the walls, which is influenced by the nature of the metallic surfaces and the temperature distribution. It is suggested that the test in its present form be dropped.

Four references.

Present Views on Nature of Detonation in Otto Cycle Engine. (C. F. Taylor and E. S. Taylor, J. Aer. Sci., Vol. 1, No. 3, July, 1934, pp. 135-136.) (8.645/29828 U.S.A.)

Time-lag in auto-ignition accounts for discrepancies between the self-ignition temperature of fuels and knock tendency as determined in the laboratory and in an engine.

Six references.

Engines, Injection and Exhaust Systems

Effect of Moderate Air Flow on the Distribution of Fuel Sprays after Injection Cut-off. (A. M. Rothrock and R. C. Spencer, N.A.C.A. Report No. 483, 1934.) (8.70/29829 U.S.A.)

From Authors' Abstract.—High-speed motion pictures were taken of fuel sprays with the N.A.C.A. spray-photographic apparatus to study the distribution of the liquid fuel from the instant of injection cut-off until about 0.05 second later.

The results show that in still air the dispersion of the fuel particles following injection cut-off was extremely slow and that the fuel tended to travel across the chamber from the injection nozzle. The best distribution was obtained by the use of air flow and a high dispersion nozzle.

Seventeen references.

Coupling for Automatic Variation of Injection Timing. Compression-Ignition Engine. (Autom. Tech. Zeit., Vol. 37, No. 19, 10/10/34, p. 513.) (8.705/29830 Germany.)

A simple automatic coupling is described. The injection timing is retarded at low engine speeds by centrifugal action. The so-called " slow speed " knock is suppressed and the engine runs quietly.

Origin of Engine Noises and Means for their Reduction—With Special Reference to Diesel Engines. (A. Schutte, W.R.H., Vol. 15, No. 21, 1/11/34, pp. 299-303.) (8.721/29831 Germany.)

There are three main sources of noise in ship installation—exhaust, induction or scavenge, and mechanical.

The air noises can be damped by the insertion of acoustic filters in the pipe line. A pipe fitted with small holes along the circumference passes high frequency sounds and damps low frequency sounds over a range determined by the size and spacing of the holes relative to the diameter of the pipe.

Another type of filter, consisting of a series of expansion boxes connected by short lengths of pipe projecting into each box, acts as a high frequency damper, according to the relation between the diameter and length of the connecting pipe and the capacity of the boxes. By a combination of these two types of silencers noises can be eliminated over the most objectionable frequency range.

Engine noise can be much reduced by careful designs of cams and piston clearance. As a last resource, in intractable cases the engine can be installed in a sound-proof compartment.

Seven references.

The Silencing of Exhaust Gas Noises of Motor Car Engines. (H. Martin, Z.V.D.I., Vol. 78, No. 43, 27/10/34, pp. 1257-1260.) (8.721/29832 Germany.)

The experiments deal mainly with the silencing of two-stroke engines. The loss in power in this case depends on the relation between the resistance characteristic of the silencer and the frequency.

Piezo electric measurements of air pressure in the exhaust confirm Kluy's theory of his filter silencer. The acoustical theory is analogous to alternating current theory.

Fourteen references.

Engine Exhaust Collector Rings. (J. Seamon, Aero Digest, Vol. 25, No. 6, December, 1934, pp. 32-36.) (8.721/29833 U.S.A.)

Collector rings must produce minimum back pressure, allow expansion of the cylinders and necessary mixture heater connection. Independent support from the aeroplane structure is often necessary.

Air heating on the Douglas DC2 is provided by an internal " intensifier " tube which supplies a small volume of very hot air.

Stainless steel and lately a nickel chrome alloy " Inconel " are the usual materials.

Engines, Pumps

S.P.C.A. Fuel Injection Pump for High Speed Engines. (L. Blériot, L'Aéron., No. 184, September, 1934, pp. 217-219.) (29834 France.)

The injection pump resembles the Bosch type, but the top of the piston is symmetrical, with two chamfered sections separated by a channel. In this way both beginning and end of injection can be controlled, giving quick release, absence of side pressure and reduced barrel wear. The pump is fitted with spring loaded ball valves.

Engines, Transmission

Whaley Infinitely Variable Gear. (Engineering, Vol. 139, No. 3611, 29/3/35, pp. 334-5.) (8.761/29835 Great Britain.)

The rotation of the primary shaft is converted into oscillatory motion by crank pin and connecting rod. The oscillatory motion is altered in a ratio controlled by a link motion of the familiar railway locomotive type and the secondary oscillation reconverted into rotary motion by a system of gear wheels. The motion transmitted by one gear wheel varies from zero to a maximum. By using double acting gear and by setting two gears at ninety degrees a comparatively steady rotatory drive is transmitted to the secondary at a mean angular speed, which is continuously variable through the whole range of feasible settings.

Sketches and photographs show details and assembly of an apparatus designed for an 8 h.p. electric motor.

The Trilok Fluid Transmission Gear. (A. Keuffel, Z.V.D.I., Vol. 78, No. 45, 10/11/34, pp. 1321-1322.) (8.761/29836 Germany.)

The Trilok fluid gear is a combination of torque converter and hydraulic coupling. Guide vanes capable of independent rotation on a free wheel mounting are interposed between the pump and turbine blades so as to form a closed circulating system. The gear transmits large starting torques as required in railway traction.

Two references.

Armament

New High Explosives. (A. Stettbacher, Z.V.D.I., Vol. 78, No. 45, 10/11/34, pp. 1309-1310.) (9.03/29837 Germany.)

Nitro-cellulose derivatives of pentrinite and hexonite have been known for some time as highly explosive powders. Their manufacture on a commercial scale has recently been made possible. Suitably blended with nitro-glycerine they produce more violent explosions than picric acid or trinitrotoluol, particularly in underwater explosions (torpedoes and mines).

Two references.

Torpedo and Bomb. (M. Ajmone-Cat, Riv. Aeron., Vol. 10, No. 8, August, 1934, pp. 203-243.) (9.02/29838 Italy.)

The technical and tactical problems of bomb and torpedo aircraft in naval warfare are discussed in general terms.

Air Torpedoes. (R. Bonomi, Riv. Aeron., No. 1, January, 1935, pp. 47-55.) (9.2/29839 Italy.)

The progress made in the design and construction of torpedoes is reviewed and their use against ships, particularly in the Battle of Jutland, is discussed.

The launching of torpedoes from aircraft is a difficult technical problem and their possible success against naval forces is largely a question of special circumstances.

Bombing attacks have much greater latitude.

No technical details are given.

Bombing During a Dive. (C. Rougeron, Revue de l'Armée de l'Air, No. 65, December, 1934, pp. 1377-1416.) (9.3/29840 France.)

The errors in a normal bombing raid (horizontal flight at great altitude) are compared with those of low altitude bombing at the end of a high speed dive.

This method of attack has been practised in the U.S.A. and the author favours its adoption.

Two references.

Ballistics. (O. v. Eberhard, Z.A.M.M., Vol. 14, No. 4, August, 1934, pp. 199-202.) (9.33/29841 Germany.)

Methods of integrating the equations of motion with various forms of expression for air resistance are discussed and some particular transformations are given with an experimental expression for air density. No numerical applications are made.

Three references.

Protection Against Fire and Gas Attacks. (B. Schiefele, Z.V.D.I., Vol. 78, No. 31, 4/8/34, p. 934.) (9.4/29842 Germany.)

The ultimate destruction of wood by fire can be considerably retarded by suitable chemical treatment. A protective layer of gas, foam or other products is formed on the surface. To be effective, both the chemicals used and the method of application must be accurately controlled.

The absorbing material in a gas mask instead of being soaked is now built up on a porous foundation of the reagent. Cut feathers (so-called " down snow ") produced efficient filters. Apparatus utilising silica gels has been designed for quick detection of obnoxious gases in small concentrations.

Clementi Goerz Bomb Sights. (Revue de l'Armée de l'Air, No. 63, October, 1934, pp. 1215-1219.) (9.62/29843 France.)

The bomber, having set the height and drift scales, keeps the target on the cross wire.

The bomb is released automatically when the sighting telescope reaches a predetermined sighting angle.

Four photographs.

Materials, Characteristics, Defects and Treatment

Influence of Magnetic Fields on the Hardness of Metals and Alloys. (A. Schulze, Z.V.D.I., Vol. 78, No. 36, 8/9/34, pp. 1069-1070.) (10.104/29844 Germany.)

The original work of Herbert showed an appreciable effect of the magnetic field on the ageing of a specimen of 100°C. The Brinell hardness was lowered approximately 100 units in certain cases.

Recent experiments have failed to reproduce his results.

Eleven references.

Cast Crankshafts. (Autom. Tech. Zeit., Vol. 37, No. 20, 25/10/34, p. 522.) (10.120/29845 Germany.)

The material used by Fords is an iron alloy of the percentage composition :— Cu 2.6, Si 2.0, C 1.3, Mn 0.5, Cr 0.4, P 0.1, S 0.05, Fe rest.

Repeated heat treatment of the originally brittle casting produces a homogeneous material of great surface hardness. The cast shafts are cheaper than forged shafts and their greater hysteresis damping gives smoother running.

Iron Oxide as Anti-Rust Pigment. (A. Schneider, Z.V.D.I., Vol. 78, No. 34, 25/8/34, pp. 1001-1002.) (10.125/29846 Germany.)

The quantity of iron oxide formed during the heat treatment of malleable iron increases with the time of exposure to high temperature. The surface film consists of varying proportions of Fe_3O_4, Fe_2O_3 and traces of C, Si, etc. Lengthy

exposure to high temperature favours the formation of the grey magnetic Fe_2O_3, which is an excellent anti-rust pigment superior to existing paints with a white pigment base.

Two references.

Rebuilding of Motor Tankship "Svithiod." (W. Scholz, Z.V.D.I., Vol. 78, No. 36, 8/9/34, pp. 1059-1060.) (10.125/29847 Germany.)

Motor tankships undergo rapid corrosion; a covering of paint is cracked by the straining of the ship and rust is formed underneath the paint. The rate of corrosion is diminished by electrolytic deposition of copper on steel and by the use of pure iron (arnico) for the tank fittings.

In the case of the "Svithiod" extensive corrosion imposed rebuilding of the central tank portion.

Three references.

Rustless Steels. (H. Bohr, Z.V.D.I., Vol. 78, No. 40, 6/10/34, pp. 1172-1173.) (10.125/29848 Germany.)

Cheap chromium steels require greater precautions against corrosion than the more expensive Cr-Ni and Cr-Mo steels. A high surface finish (polish) delays the attack of corrosion in every case.

Influence of Oxide Films on Wear of Steels. (S. J. Rosenberg and L. Jordan, Bur. Stan. J. Res., Vol. 13, No. 2, August, 1934, pp. 267-280.) (10.125/29849 U.S.A.)

From Authors' Abstract.—Steels with 0.43, 0.81 and 1.36 per cent. carbon were tested. It was found that when the steels were hardened and subsequently tempered at low temperatures, the rates of wear were comparatively low; the wearing surfaces were smooth and were covered by a thin oxide film and the abraded particles consisted of Fe_2O_3 and Fe_3O_4. When these steels were tempered above certain temperatures, the rates of wear were extremely high.

Tests indicated that a film of either ferric or ferroso-ferric oxide on the wearing surfaces of carbon steels results in a certain degree of protection against wear, probably by preventing actual metal to metal contact.

Metallographic Investigations on the Destructive Effect of Cavitation. (H. Schröter, Z.V.D.I., Vol. 78, No. 40, 6/10/34, pp. 1161-1162.) (10.125/29850 Germany.)

The destruction is attributed to impulsive pressures produced by the collapse of cavities.

Four references.

Electric Spot Welding in Aircraft and Automobile Construction. (K. Ruffin, Z.V.D.I., Vol. 78, No. 47, 24/11/34, p. 1389.) (10.140/29851 Germany.)

Stainless and austenitic steels can be spot welded together and the combination is widely used in American and Russian aircraft.

In welding light alloys careful regulation of current density is required to prevent the accumulation of a high resistance oxide film subject to explosive disruption accompanied by sputtering of the metal.

Three references.

The Welding of High Tensile Steels According to Experiences Gained in Aircraft Construction. (J. Müller, L.F.F., Vol. 11, No. 4, 1/10/34, pp. 93-103.) (10.140/29852 Germany.)

Two principal difficulties are experienced in welding high tensile steels:—

(1) Cracks form in the metal in the neighbourhood of the weld during the welding process at temperatures between 800°C.—1000°C.

(2) The material in the immediate neighbourhood of the weld becomes brittle after cooling down.

The cracks are mainly due to welding stresses, but are favoured by impurities in the steels (phosphorous and sulphur). Brittleness is associated with too rapid cooling of the work and by the presence of Mn and by excessive C content. Cracks and brittleness are not necessarily connected and may occur separately.

Eight references.

Stainless Steel Working and Welding—Tube Bending—Radiator Soldering. (D. G. Lingle, Air Corps In. Circ., Vol. 7, No. 696, 8/9/34.) (10.140/29853 U.S.A.)

Workshop specifications are given for annealing, drawing, spinning and welding stainless steel (one photograph).

Methods are given of bending steel and alloy tubes, filled or unfilled (one photograph, three curves of changes in wall thickness).

Directions are given for radiator core dipping in a high melting point solder bath (two photographs).

Wrought Magnesium Alloys. (W. E. Prytherch, Engineering, Vol. 139, No. 3611, 29/3/35, pp. 343-4; Engineer, 29/3/35, p. 324.) (10.232/29854 Great Britain.)

The mechanical and working properties of various binary, ternary and quaternary alloys are given briefly. The scaling difficulty can be met in different ways.

Protective Value of Nickel and Chromium Plating on Steel. (W. Blum, P. W. C. Strausser and A. Brenner, Bur. Stan. J. Res., Vol. 13, No. 3, September, 1934, pp. 331-355.) (10.262/29855 U.S.A.)

Authors' Abstract.—Exposure tests of plated steel were conducted in rural, suburban, industrial and marine locations. It was found that the thickness of the nickel layer is more important than any other factor. An intermediate layer of copper decreases the protective value of thin deposits, but is not detrimental in thick coatings, especially if they are chromium plated. The customary thin chromium coatings (0.00002in. or 0.0005 mm.) increase the resistance to tarnish, but not the protection against corrosion.

Fifteen references.

Weathering of Aluminium Alloy Sheet Materials Used in Aircraft. (W. Mutchler, N.A.C.A. Report No. 490, 1934.) (10.262/29856 U.S.A.)

From Author's Abstract.—The report contains results obtained in an extensive series of weather exposure tests, which reveal the extent to which the resistance of the materials to corrosion was affected by variable factors in their heat treatment and by the application of various surface protective coatings.

The results indicate that the sheet materials are to be regarded as thoroughly reliable provided proper precautions are taken to render them corrosion resistant.

Seventeen references.

Eloxal Process—Electrolytic Oxidation of Aluminium and its Alloys. (H. Schmitt, A. Jenny and G. Eissner, Z.V.D.I., Vol. 78, No. 52, 29/12/34, pp. 1499-1506.) (10.262/29857 Germany.)

A number of patents covering the electrolytic oxidation of aluminium have been pooled in the Eloxal process. The electrolyte consists mainly of chromic or oxalic acid and the oxide layer is formed by immersion or spraying.

The process receives extensive application in containers for milk, beer and preserves.

Six references.

On the Formation of Protective Films on Copper. (W. Haase, Z. Metallk., Vol. 26, No. 8, August, 1934, pp. 185-188.) (10.262/29858 Germany.)

The natural protective film on copper consists of cuprous oxide. The green patina observed on exposure to the atmosphere consists mainly of basic copper chloride and sulphate.

Photographs are reproduced showing different types of corrosion.

Twelve references.

Formula for Determining Variation in Density of Timber with Variable Humidity. (F. Kollmann, Z.V.D.I., Vol. 78, No. 48, 1/12/34, pp. 1399-1401.) (10.400/29859 Germany.)

It is important to determine the changes in weight which various timbers undergo in storage during artificial drying or in rail transit.

A physical investigation is made of the process underlying water absorption and a chart is constructed from which numerical estimates of density may be made.

Instrument for Measurement of Moisture in Wood. (J. Sci. Inst., Vol. 12, No. 3, March, 1935, p. 95.) (10.400/29860 Great Britain.)

A condenser is charged to 600 volts by hand generator and is then discharged through a block of wood of standard size with electrodes at definite positions. The rate of discharge is a measurement of the moisture, with a claimed accuracy of $\frac{1}{2}$ per cent. for a range 3 to 18 per cent. moisture.

Ceramic Insulating Materials for High Frequency. (H. Handrek, Z.V.D.I., Vol. 78, No. 50, 15/12/34, pp. 1441-1449.) (10.406/29861 Germany.)

The new materials contain magnesium and titanium oxides. Titanium oxide porcelains have been obtained with a dielectric coefficient as high as 80 (compared with five for ordinary porcelain) and a temperature coefficient of opposite sign and roughly the same order as that of ordinary porcelain. A suitable combination of the two materials gives a capacity insensitive to temperature variations.

Fifteen references.

Testing Apparatus and Methods of Testing

The Toepler Striation Method Applied to Phenomena of Flow. (H. Schardin, Z.V.D.I., Vol. 78, No. 46, 17/11/34, pp. 1351/1352.) (11.105/29862 Germany.)

The striation method of Toepler can be employed either as a pure shadow method or an optical system can be employed to reproduce the striations. Generally speaking, only the latter method gives quantitive results (see Abstract 29502).

In certain cases the simpler shadow method can be employed and Schmidt (see Abstract 26027) applies it to the estimation of the heat transfer between a heated tube and air.

Examples of both methods are reproduced.

New Whirling Arm. (Th. Troller, J. Aer. Sci., Vol. 1, No. 4, October, 1934, pp. 195-197.) (11.12/29863 U.S.A.)

The arm has a radius of 32 feet and a maximum velocity of 170 m.p.h. (75 m. per sec.). The cyclic flow set up by the arm is heavily damped by gauze screens with openings for the passage of the test object.

Constructional details are given with two photographs and three sketches.

A Belt Method of Representing Ground. (A. Klemin, J. Aer. Sci., Vol. 1, No. 4, October, 1934, pp. 198-199.) (11.16/29864 U.S.A.)

The introduction of a fixed plate to represent the ground below a model in the wind channel sets up disturbances not present in aeroplane flight over the ground in still air. A method of sucking away the boundary layer and feeding in new air to replace it introduces further complications. These difficulties are removed by the use of a travelling belt running on rollers, the upper side moving with the air flow. Trial runs have given satisfactory results.

Experimental Verification of Theodorsen's Theoretical Jet-Boundary Correction Factors. (G. Van Schliestett, N.A.C.A. Tech. Note No. 506, October, 1934.) (11.16/29865 U.S.A.)

From Author's Abstract.—This report presents the results of wind tunnel tests conducted at the Georgia School of Technology for the purpose of verifying the five cases analysed by Theodorsen.

The tests were conducted in a square tunnel and the results constitute a satisfactory verification of his general method of analysis. During the preparation of the data two minor errors were discovered in the theory and these have been rectified.

Thirteen references.

Installation at the Aero and Hydrodynamic Laboratory at Lille. (A. Martinot-Lagarde, L'Aéron., No. 185, October, 1934, pp. 236-240.) (11.20/29866 France.)

The water channel, 22 metres long, 1.5 metres wide and 1.55 metres deep, is extensively fitted with glass panels for visual observation. A carriage speed of 4 metres per second can be maintained for 8 metres. The maximum speed is 15 metres per second, acceleration and deceleration about g and 2g respectively.

The wind channel of the Eiffel type has an open jet of 2.2 metres diameter and maximum air speed of 60 metres per second. The power absorbed is 200 h.p. No guide vanes are required in the return channel, the exit diffusor (carrying the fan) being close to the end wall.

Complete Tank Tests of Two Flying Boat Hulls with Pointed Steps—Models 22-A and 35. (J. M. Shoemaker and J. W. Bell, N.A.C.A. Tech. Note No. 504, September, 1934.) (11.22/29867 U.S.A.)

From Authors' Abstract.—Take-off examples are worked out using data from these tests and a previous test of a conventional model applied to an arbitrary set of design specifications for a 15,000 pound flying boat. The comparison of these examples shows both pointed-step models to be superior to the conventional form and Model 35 to be the better of the two.

Model 35 is applied to a hypothetical 100,000 pound flying boat of the twin-hull type and performance calculations are made both for take-off and range. The results indicate that the high performance of this type of hull will enable the designer to use higher wing and power loading than are found in current practice, with a resulting increase in range and pay load.

Seven references.

Tank Tests of Flat and V-bottom Planing Surfaces. (J. M. Shoemaker, N.A.C.A. Tech. Note No. 509, November, 1934.) (11.22/29868 U.S.A.)

From Author's Abstract.—Four planing surfaces were tested. The results cover a wide range of speeds, loads and trim angles. The data are analysed to determine the characteristics of each surface at the trim angle giving minimum resistance for all the speeds and loads tested. A planing coefficient intended to

facilitate the application of the results to design work is developed and curves of resistance, wetted length and centre of pressure are plotted against this coefficient.

Several examples, showing the application of the test data to specific design problems, are included.

Ten references.

The Influence of Shape on Performance of Sea-going Vessels. (Z.V.D.I., Vol. 78, No. 50, 15/12/34, pp. 1449-1452.) (11.22/29869 Germany.)

The article is a resumé of papers read before the Hamburg Shipbuilding experimental station, including the action of waves on self-driven models and tests of manœuvrability of a large model.

It is hoped to reduce the number of designs by the exchange of practical experience.

Twenty references.

Hull Design. (S. Truscott, Aviation, Vol. 33, No. 8, August, 1934, pp. 250-252.) (11.22/29870 U.S.A.)

A brief review is given of the problem of hull design and the *rôle* of the test tank in solving hydrodynamical problems.

Spectroscopical Methods of Chemical Analysis. (H. Moritz, Z.V.D.I., Vol. 78, No. 50, 15/12/34, pp. 1453-1456.) (11.40/29871 Germany.)

A description is given of spectroscopic apparatus for testing engineering materials. An example is given of Cr determination in a steel by the spectral photometer and reference spectra.

Seven references.

Sensitivity of X-Ray inspection of Metal Defects. (L. E. Abbott, Bell Tele. Tech. Pubcn. B-803, 1934.) (11.47/29872 U.S.A.)

An account is given of quantitative measurement of dimensions, cracks, inclusions, etc. Two X-ray photographs taken at right angles determine the length and orientation of the crack. Photographs taken along the greatest length of the crack may succeed where those at other orientations fail to give a photographic record.

In general the limit of X-ray inspection with a 200,000 volt tube is about two or three inches of steel, after which gamma ray inspection extends the range. There is a difference of opinion on the exact thickness at which the latter should supersede the former.

Photographs are reproduced and a calibration curve is given.

Testing of Metals by Mesothorium Radiation. (M. Widemann, Z. Metallk., Vol. 26, No. 9, September, 1934, pp. 204-206.) (11.47/29873 Germany.)

The mesothorium preparation produces a point source of gamma radiation suitable for the inspection of thick metal objects for which X-ray investigation becomes very expensive. Typical photographs are reproduced.

Six references.

Airships, Balloons, etc.

Ascension to Stratosphere by U.S.A. Balloon "Explorer." (P. Léglise, L'Aéron., No. 185, October, 1934, pp. 241-247, and No. 186, November, 1934, pp. 273-276.) (12.19/29874 France.)

Details are given of the construction of the balloon and the ascent. The envelope tore near the estimated ceiling (60,000 feet). After a gradually

accelerated descent to 6,000 feet the three passengers escaped by parachutes. The gondola and most of the apparatus were wrecked. A remarkable film of the last stage of the descent was taken by an aeroplane.

Illustrations are reproduced.

The Stalling of Airships. (W. B. Klemperer, J. Aer. Sci., Vol. 1, No. 3, July, 1934, pp. 113-122.) (12.30/29875 U.S.A.)

Stalling is an aerodynamic phenomenon affecting the dynamic lift and drag. Airships with considerable dynamic lift exhibit the phenomenon of stalling. If the buoyancy is equal to the weight, stalling can only be produced by the sudden application of large elevator moments. The manœuvres for recovering from a stall depend on the causes of the disturbing moments, whether extraneous or internal and the corresponding movements of the control may be direct or reversed.

Instruments are required to show the cause of the disturbance so that the pilot can act quickly. At present too much depends on the experience of the commander.

Wireless

Limits to Amplification. (J. B. Johnson and F. B. Llewellyn, Bell Tele. Pubcn. B-838.) (13.2/29876 U.S.A.)

The sources of noise in amplifiers are stated and discussed briefly. A short account is given of sources of noise other than the amplifier.

Forty-three references.

Electro-Magnetic Radiations. (Lord Rutherford of Nelson, Engineering, Vol. 139, No. 3611, 29/3/35, pp. 341-2.) (13.30/29877 Great Britain.)

Energy distributions of black body radiation for wave lengths up to 300 mu are shown graphically. Long wave radiations can be reflected from and refracted by quartz screen and lenses. Waves longer than one mu are almost completely cut off by a layer of water.

North Atlantic Ship-Shore Radiotelephone Transmission during 1932/33. (C. N. Anderson, Proc. Inst. Rad. Eng., Vol. 22, No. 10, October, 1934, pp. 1215-1224.) (13.31/29878 U.S.A.)

Author's Abstract.—This paper extends the analysis of ship-shore radio transmission data for an additional two-year period beyond that reported on in a previous paper (see Abstract 26587).

Contour diagrams show the variation of signal field with time of day and distance for the winter, summer, spring, and fall seasons and for the approximate frequencies 4, 18 and 13 megacycles.

A comparison is made with the data obtained during 1930 and 1931. In general transmission during 1932/33 tends to be somewhat better on frequencies below about 9 megacycles and somewhat poorer on frequencies above 9 megacycles. At 4 megacycles the increase is of the order of 10 decibels, and for 13 and 17 megacycles, the decreases are about 6 and 10 decibels respectively.

Improved Aircraft Radio Beacon. (Aero Digest, Vol. 25, No. 6, December, 1934, p. 48.) (13.4/29879 U.S.A.)

Skyward radiation is reduced by the use of four vertical antennæ at each station. Interference between the original beacon wave travelling along the ground and reflected sky waves is reduced and reception is improved.

Emission of Electrons from Cold Metals. (C. C. Chambers, J. Frank. Inst., Vol. 218, No. 4, October, 1934.) (13.5/29880 U.S.A.)

Previous experimental work is reviewed critically and anomalies are referred to welded supports and to changes in the surface conditions of the wire specimens.

Helium Glow Lamp Current Indicator. (Z.V.D.I., Vol. 78, No. 35, 1/9/34, p. 1042.) (13.5/29881 Germany.)

The glow lamp is fitted with a straight wire cathode surrounded at its lower end by a ring-shaped anode. The glow along the cathode increases with the lamp current. There is no lag in the indications, which makes the lamp suitable for oscillography. It has received application as a tuning indicator in wireless sets.

One reference.

The Construction of High Vacuum Cathode Ray Tubes for Television and Measuring Purposes. (M. Ardenne, H.F. Technik, Vol. 44, No. 5, November, 1934, pp. 166-173.) (13.5/29882 Germany.)

The influence of anode current and anode potential on spots of various size is examined and an electrostatic accelerating circuit is described. An illustration shows a modern valve, 60 cm. long. The diameter of the spot of $\frac{3}{4}$ mm., the normal picture size 13 by 18 cm. and the sensitivity 3 mm. deflection per volt.

Fifteen references.

Vacuum Tubes as High Frequency Oscillators. (M. J. Kelly and A. L. Samuel, Bell Tele. Pubcn. B-839.) (13.5/29883 U.S.A.)

The negative grid, the protective grid of Barkhausen, and the so-called magnetron oscillators are considered in reference to frequencies above 100 megacycles.

The electro-magnetic coupling becomes increasingly complex with increasing frequency and empirical knowledge is in advance of mathematical physical theory.

The construction of various types of tube is shown in twelve photographs. Diagrams of circuits and experimental characteristics are given graphically.

The accepted elementary physical relations are stated and the ground is prepared for further development of theory.

Twenty-seven references.

Gas Filled Cathode Ray Tubes for Television. (F. Michelssen, H.F. Technik., Vol. 44, No. 3, September, 1934, pp. 95-100.) (13.5/29884 Germany.)

In its applications to television the cathode ray beam is subjected to periodic variations both of intensity and direction.

The author describes various patented circuits. Difficulties of technique in the formation and adhesion of fluorescent films are discussed.

Twenty-five references.

Experimental Investigation of the Disturbing Night Effect on Wireless Direction Finding. (Pt. I, G. Barkowitz, H.F. Technik., Vol. 44, No. 5, November, 1934, pp. 174-178, and Pt. II, A. Hagen, No. 6, December, 1934, pp. 181-185.) (13.6/29885 Germany.)

PART I.—Apparatus is described for continuous registration of D/F response. It was found that waves of 260-680 m. were subject to greater and more frequent disturbances than waves of 1,400-2,000 m., but there were generally intermediate periods when correct direction was given.

Fifteen references.

PART II.—Modifications are described which improve the accuracy of the receiving antenna circuit. An inclination of the plane of the frame aerial to the horizon is generally beneficial.

The superiority of the Adcock antenna is demonstrated.

Four references.

Interference in Reception of Short Waves by the Ignition System of Combustion Engines. (A. Neubauer, H.F. Technik., Vol. 44, No. 4, October, 1934, pp. 109-118.) (13.6/29886 Germany.)

The range of interference depends on size of engine and may extend to several thousand feet. A resistance of the order of 15,000 ohm placed at the spark plug terminal is most effective in reducing the effect.

Reference is made to an article, L. F. Curtiss on "Electrical interference in motor car receivers" (Proc. I.R.E., Vol. 20, No. 4, April, 1932), which deals with similar problems for longer wave lengths.

Twenty-five references.

Production and Application of Ultra Short Undamped Electric Waves. (H. E Hollmann, H.F. Technik., Vol. 44, No. 2, August, 1934, pp. 37-60.) (13.6/29887 Germany.)

By decreasing the dimensions of standard valves, shorter waves can be produced, down to 50 cm. wave length. For shorter waves special circuits have to be devised in which vibrating electrons become the source of the radiation. The additional range of frequency is available for signalling, television, cross channel navigation, etc.

The short waves are refracted by the water vapour in the air. They have been extensively employed in the study of molecular structure by anomalous dispersion.

Forty figures and 84 references.

Television by Electron Image Scanning. (P. T. Farnsworth, J. Frank. Inst., Vol. 218, No. 4, October, 1934, pp. 411-444.) (13.7/29888 U.S.A.)

An optical image is focussed on a uniform photo-electric surface (caesium-silver oxide) with a sensitivity of 50-65 micro-amperes per lumen. The surface is scanned by a focussed beam of electrons and the released electron stream is multiplied by additional caesium-silver oxide surfaces. The problem of synchronising transmitter and receiver is discussed briefly.

The received signals operate a cathode tube emitting an electron beam focussed by an air-core coil on a fluorescent screen. Electrostatic deflection is feasible. The anode and cathode operate at 4,200 volts. Photo-electric current and illumination characteristic are given graphically. Two reception images are reproduced.

Photocells Used in Light Controlled Machines and Apparatus. (W. Kluge and H. Briebrecher, Z.V.D.I., Vol. 78, No. 31, 4/8/34, pp. 935-938.) (13.7/29889 Germany.)

Descriptions are given of the alkali cell, the selenium resistance cell and the transition layer cell. Resistance to external E.M.F. diminishes with increase in light intensity, linearly in the alkali cell, and non-linearly in the selenium cell.

The transition layer cell generates E.M.F. internally under the influence of light in analogy with the thermo-couple under the influence of heat.

The selenium cell exhibits the greatest sensitivity to small light intensity, but reaches saturation at comparatively low intensity, beyond which its performance is inferior to that of the transition layer type.

The alkali cell has a linear characteristic, but its output is considerably below that of the other two. Its advantages are constancy of calibration, quickness of response, robustness and sensitivity to infra-red rays.

Diagrams of typical circuits are given for the three types of cells.

Seven references.

Modern Aircraft Radio Equipment. (Flight, Vol. 27, No. 1368, 14/3/35, pp. 274-279.) (13.97/29890 Great Britain.)

In a summary of radio equipment as installed in military and commercial aircraft brief specifications are given, with photographs, sketches and a diagram of connections.

Acoustics, Noise Reduction, etc.

Balloon Theodolite for Observations from Land and Ships. (W. Schnittger and H. Linke, Z. Instrum., No. 9, September, 1934, pp. 311-317.) (15.10/29891 Germany.)

These instruments are intended for medium altitudes and are characterised by ease of manipulation, since the reading points for azimuth and altitude are immediately below one another. The accuracy is 1/10°. For observation from a ship a reflection of the horizon is provided. Alarm clocks give time signals for taking readings, preceded by a " ready " signal.

Sound Absorption in Acoustic Filters. (E. Grossmann, Ann. d. Phys., Vol. 21, No. 4, December, 1934, pp. 433-442.) (15.20/29892 Germany.)

The physical theory is given in Waetzmann's form. Numerous measurements are plotted in comparison with calculated values and show substantial agreement.

Five references.

Dependence of Sound Absorption upon Area and Distribution of Absorbent Material. (V. L. Chrisler, Bur. Stan. J. Res., Vol. 13, No. 2, August, 1934, pp. 169-187.) (15.20/29893 U.S.A.)

When part of the surface of a chamber is highly absorbent relatively to the rest of the surface the distribution of wave energy appears to become heterogeneous and the decay ceases to be logarithmic. Examples are given graphically.

The Sabine formula may succeed for more or less acoustically similar spaces, although it does not describe the physical realities. Where the acoustical dissimilarity is great the differences may not average out and predictions based on the Sabine formula may fail seriously.

Three references.

Air Soundings. (L. Laboureur, Rev. de l'Armée de l'Air, No. 61, August, 1934, pp. 867-882.) (15.20/29894 France.)

A descriptive technical account is given of the Laboureur-Dubois sounding apparatus, illustrated by seven photographs, two diagrams of connections and a sketch showing the installation on an aeroplane.

A siren emits notes of frequency 1,500 duration 1/100th second. The ground echo is received by a microphone. The signal illuminates a neon lamp and the echo extinguishes it. The duration of illumination, which may be from 1/100th seconds to two seconds, is indicated on a dial calibrated to corresponding heights.

Two series of readings are given, one showing a rise from ground level to 250 metres and return, the other showing the variations during horizontal flight over rising ground. The smallest height measurable is about 5 metres, with the selected signal duration.

Characteristics of Microphones. Part I. (K. Sato, H. Kawai and R. Tate, Aer. Res. Institute, Tokyo, Report No. 110 (Vol. 9, No. 2), August, 1934.) (15.26/29895 Japan.)

From English Abstract.—A sketch shows the test installation with position of microphone and Rayleigh disc in a sound-proof chamber.

Diagrams of connections are given for different types of microphones and characteristics are plotted graphically.

The Importance of Sound Transmission through Solids in the Acoustic Properties of Rooms and Buildings. (E. Meyer, Z.V.D.I., Vol. 78, No. 32, 11/8/34, pp. 957-963.) (15.38/29896 Germany.)

In a concert hall the air transmits the greater part of the sound energy received by the audience and the wall material has a relatively small effect. The transmission of sound from one room to another through the structure of the building, depends largely on the materials.

Sound insulation is obtained by using materials of low sound conductivity or by the provision of reflectors or sound absorbing material at certain points only. An installation is described which determines the damping of the insulating material numerically.

Thirteen references.

Air Navigation

Recent Developments in Astronomical Observations during Flight. (A. Bastide, L'Aéron., No. 185 (Bulletin), October, 1934, pp. 89-97.) (15.5/29897 France.)

Various proposals are briefly reviewed in respect of small weight and size of the apparatus and simplicity, rapidity and accuracy of operation. No single method combines all these requirements. Preference is given to Kahn's method by observation of altitude only of sun or star, with the disadvantage of special and extensive maps, which require redrawing every two years for the sun and every five years for the stars.

Reference is made to the Guyot mechanism (see Abstract 29898), which is considered too cumbersome.

A New Apparatus for Rapid Position Finding from Astronomical Observations taken on Aircraft. (Capt. Guyot, L'Aéron., No. 184 (Bulletin), September, 1934, pp. 73-81.) (15.5/29898 France.)

The procedure of position finding involves the following operation, as well as the use of special charts:—

(1) Identification of a particular star.
(2) Determining its altitude at a known time (M).
(3) Correcting the altitude.
(4) Determining the terrestrial co-ordinates of the projected star position at time M.
(5) Determining altitude and azimuth corresponding to centre of special chart.
(6) Tracing relative altitude circle on special chart.

The apparatus carries out operations (3) to (6) mechanically.

Accidents and Precautions

Protection of Large Oil Store against Air Attack. (R. v. Feld, Z.V.D.I., Vol. 78, No. 39, 29/9/34, p. 1146.) (16.00/29900 Germany.)

Underground tanks 10 feet below the earth surface and with one or two layers of concrete or wire netting interposed are adequately protected against bomb

attack. Alternatively tanks on ground level may be protected by earthworks. Distilling towers and other prominent plant equipment should be scattered to isolate the damage.

Two references.

Fire Danger in Passenger Ships. (Z.V.D.I., Vol. 78, No. 47, 24/11/35, p. 1367.) (16.00/29901 Germany.)

It is proposed that the furnishings of selected blocks of cabins on each deck be effectively fireproofed as checks to the spread of fire without the expense of fireproofing the whole ship.

Two references.

Mobile Supply Column "Bayern." (Z.V.D.I., Vol. 78, No. 47, 24/11/34, p. 1388.) (16.00/29899 Germany.)

As a precaution against large scale explosion or fires a supply column has been organised and equipped with high speed lorries carrying field kitchens and field medical equipment with supplies. Three thousand rations and 5,000 gallons of tea or coffee can be supplied daily.

Aircraft, Unorthodox

Historical Notes. (L'Aerotecnica, Vol. 14, No. 8/9, August/September, 1934, pp. 1047-1065.) (17.00/29902 Italy.)

Twenty-six photographs show details of models of models of flying machines constructed in the 15th and 16th centuries by Leonardo da Vinci and others.

Landing Characteristics of an Autogiro. (W. C. Peck, N.A.C.A. Tech. Note No. 508, November, 1934.) (17.05/29903 U.S.A.)

Author's Abstract.—An investigation to determine the rate of descent, the horizontal velocity, and the attitude of contact of an autogiro in landings was made by the N.A.C.A. The investigation covered various types of landings.

The results of the investigation disclosed that the minimum rate of descent at contact with the ground (10.6ft. per sec.) was less than the minimum rate of descent attainable in a steady glide (15.8ft. per sec.); that the rates of descent at contact were of the same order of magnitude as those experienced by conventional aeroplanes in landings; that flared landings resulted in very low horizontal velocities at contact, and that unexpectedly high lift and drag force coefficients were developed in the latter stages of the flared landings.

Three references.

(Flaring = flattening out of flight path.)
(Flared landing = landing with abrupt flattening out.)

Direct Start Autogiro. (J. de la Cierva, Flight, Vol. 27, No. 1369, 21/3/35, pp. 308-310, and Aeroplane, No. 1243, 20/3/35, pp. 330-332.) (17.05/29904 Great Britain.)

Lengthy extracts are given from a paper read before the Royal Aeronautical Society.

A description is given of the comparatively simple mechanism, whereby the incidence of the blades is kept at zero during run up by direct drive and increased to effective flying incidence on de-clutching.

A jump to 20 feet is mentioned as sufficient for starting purposes. The autogiro then climbs at its normal path angle.

A sketch shows the flexible mounting of the blades.

Two photographs show an autogiro rising from and alighting on the Italian cruiser "Fiume."

An Aerodynamic Analysis of the Autogiro Rotor with a Comparison between Calculated and Experimental Results. (J. B. Wheatley, N.A.C.A. Report No. 487, 1934.) (17.05/29905 U.S.A.)

From Author's Abstract.—An extension of the autogiro theory of Glauert and Lock is presented in which the influence of a pitch varying with the blade radius is evaluated and methods of approximating the effect of blade tip losses and the influence of reversed velocities on the retreating blades are developed. An approximate evaluation of the effect of parasite drag on the rotor blades established the importance of including this factor in the analysis.

Five references.

The Rotary Wing. (E. Everling, Luftwissen, Vol. 1, No. 8, 15/8/34, pp. 221-224.) (17.10/29906 Germany.)

The Rohrbach wings are of the paddle wheel type. A double cam drive controls the feathering of the blades. In case of engine failure, the wing system autorotates. Aerodynamically the design is promising. (N.A.C.A. Technical Note No. 467.) The mechanical details of the drive may present difficulties.

Eight references.

Influence of Aerodynamical Refinements on Glider Performance. (A. Lippisch, L.F.F., Vol. 11, No. 5, 25/10/34, pp. 122-127.) (17.40/29907 Germany.)

Formulæ for horizontal and vertical components of glide velocity are given in normal and in simplified form. Relations between gliding angle, wing loading, vertical velocity component and profile resistance are shown graphically. Optimum conditions are obtained by integration of the vertical component over its mean range.

The elementary, but rather complicated expressions, are exhibited graphically for ranges of values of the vertical component and mean profile resistance, so that the best compromise can be chosen. Two gliders are compared and show a notable advance in performance obtained, particularly by careful filleting of wings and body.

Seven photographs show structural details, finish and appearance in flight.

Convection Current Gliding. (W. Georgii, L.F.F., Vol. 11, No. 5, 25/10/34, pp. 117-121.) (17.40/29908 Germany.)

An elementary account is given of the origin and nature of convection currents in the atmosphere. Diagrams show lapse rates up to 500 m. under varying conditions of radiation, absorption, evaporation and condensation over land and sea. A map of the Rhön gliding competition shows four glides of over 300 km. in a west wind of 45 to 50 km. per hr. at 1,000 to 2,000 m. height.

Warm moist air from the South Atlantic transported thermal energy which was released over the Rhön district by condensation with concomitant cloud formations and rising convection currents which were utilised by the gliders.

Barograms of the four glides are reproduced.

Influence of Weight and Resistance on Vertical Component and Gliding Ratio of Gliders. (R. Kosin, L.F.F., Vol. 11, No. 5, 25/10/34, pp. 128-130.) (17.40/29909 Germany.)

In supplement to the previous paper by Lippisch, more general standard formulæ are written down and typical numerical examples are shown graphically.

Rules are given for proceeding to optimum values of the glider characteristics.

Aircraft Carriers

Mothership "Schwabenland." (Luftwissen, Vol. 1, No. 8, 15/8/34, pp. 225-227.) (18.04/29910 Germany.)

The motor ship "Schwabenland" of 8,000 tons displacement has been designed as a tender ship on the Gambia-South America route of the Lufthansa. The installation is similar to that of the "Westfalen" and it is intended to use one ship at either end of the long sea passage for catapult starting.

Lufthansa Aircraft Carrier for the South Atlantic Air Service. (E. Foerster, W.R.H., Vol. 15, No. 22, 15/11/34, pp. 330-334.) (18.04/29911 Germany.)

Photographs and drawings show the aircraft mothership "Schwabenland" and the aircraft hoisting equipment. The hoisting-in of a seaplane, by the stern crane, is shown in a calm sea, the "trailing sheet" not being in use.

Meteorology and Physiology

Meteorological Transatlantic Service. (J. H. Kimball, Aviation, Vol. 33, No. 8, August, 1934, pp. 244-245.) (19.10/29912 U.S.A.)

A map of the North Atlantic shows land stations and a typical distribution of reporting ships. The steamer route is well reported, but the flying route over Labrador, Greenland, Iceland and the North of Scotland is sparsely covered.

An account is given of the international machinery for collection and broadcasting.

A New Hygrometer Using a Cellophane Membrane. (H. Bongards, Z. Instrum., No. 9, September, 1934, pp. 322-323.) (19.10/29913 Germany.)

Cellulose membranes known as "cellophane" are permeable to water vapour, but impermeable to air, and withstand pressure differences of the order of one atmosphere. A U-tube, partly filled with mercury, has one limb closed by a cellophane membrane, and a difference of level is established and measures the vapour pressure of the air directly.

The Goodrich De-icing System for Aircraft. (Tech. Aéron., No. 134, 1934, p. 211.) (19.15/29914 France.)

Rubber bags are fitted to conform to the general wing contour. A periodic inflation, about twice a minute, cracks off the ice.

The airscrew is protected by rubber pads soaked in a mixture of castor oil, resin and di-ethyl phtalate, the hub being shielded by a spinner. The outer blade section needs no protection, the high centrifugal force preventing ice formation.

De-icing Wings. (Aeroplane, Vol. 48, No. 1241, 6/3/35, p. 276.) (19.15/29915 Great Britain.)

A brief description is given of the Goodrich de-icing equipment fitted to the leading edge of the wing and the method of operation is illustrated by four sketches.

Physical Effects and Diseases of Flying Personnel Due to Exceptional Fatigue Under Service Conditions. (Dr. Flamme, Rev. de l'Armée de l'Air, No. 62, September, 1934, pp. 987-1019.) (19.29/29916 France.)

The physiological strain of flying is great. Cold, vibration, noise, smell, etc., contribute to weaken the constitution and the pilot must occupy his spare time in a healthy manner to maintain his fitness.

If the medical entrance is to be made easier, in order to pass the necessary number of candidates, subsequent medical control is essential.

Acceleration Effects on the Labyrinth of the Ear in a Spin. (H. v. Diringshofen, L.F.F., Vol. 11, No. 5, 25/10/34, pp. 150-151.) (19.29/29917 Germany.)

Reference is made to physiological sensations recorded by G. Schubert in a medical journal. By shaking his head violently he produced so-called " blackening out " or loss of vision due to failure of blood supply to the retina.

The author repeated the experiment without obtaining results. Strips of cinema film are reproduced showing the amplitude of the motion, the period being given by the rate of exposure, 15 per second.

The accelerations and physiological effects of spins are recorded and discussed. Three references.

Lighting

Electric Installations in Commercial Aircraft. (H. Beckert, Luftwissen, Vol. 1, No. 12, 15/12/34, pp. 345-347.) (21.0/29918 Germany.)

The weight of the electrical installation is between 2 and 5 per cent. of the net weight of the Junkers commercial aircraft. It includes ignition, wireless and navigation lights, engine starting, changing of airscrew pitch and operation of landing gear.

All instruments operated electrically must be added to the list.

Photometric Standards of Tungsten Lamps. (H. T. Wensel and others, Bur. Stan. J. Res., Vol. 13, No. 2, August, 1934, pp. 161-168.) (21.07/29919 U.S.A.)

Disagreements in international comparisons are due to the photometric calibration of tungsten lamps from carbon filament lamps, without due regard for variability of chromatic intensity perception in different subjects. The relative intensity of red and green colour sensation in two subjects, both with normal vision, varied by as much as 5 : 1. By taking average values of sensation intensity from a large number of observers it is considered that sufficient accuracy is obtainable to bring stepped-up standards into agreement within 1 per cent.

A physical method is based on photometric comparison of carbon lamps with a black body immersed in freezing platinum (2,047°K.) and of gas-filled tungsten lamps with a black body immersed in freezing iridium (2,722°K.). An empirical formula is given for the brightness of a black body from 1,530 to 2,727K.

Fourteen references.

Aerodynamics and Hydrodynamics

Hydrodynamics—Principle of Minimum Dissipation in a Viscous Fluid, with Application to the Sun's Angular Velocity. (G. Dedebant, Ph. Schereschewsky and Ph. Wehrle, Comptes Rendus, Vol. 199, No. 23, 3/12/34, pp. 1287-1289.) (22.0/29920 France.)

Assuming a constant coefficient of turbulent velocity the author writes down an expression for the dissipation, applies the conditions of invariance and deduces a differential equation for the vorticity of an element in terms of its radius of rotation.

A formal solution is written down and values computed therefrom agree with observed rotation at the surface more closely than previous expressions.

Path and Stability of a Vortex Moving Round a Corner. (A. Miyadzu, Phil. Mag., Vol. 19, No. 127, March, 1935, pp. 644-660.) (22.0/29922 Great Britain.)

In supplement to the previous papers (see Abstracts Nos. 27153 and 29921) eight examples are given of plane boundaries with angular discontinuities. The

velocities are expressed in bipolar co-ordinates in terms of elementary functions only.

The methods of conformal transformation are used throughout.

Path and Stability of a Vortex Moving Round a Corner. (A. Miyadzu, Phil. Mag., Vol. 17, No. 115, May, 1934, pp. 1010-1023.) (22.0/29921 Great Britain.)

In extension of a previous paper (Abstract 27153) expressions are formed for the velocities in complex co-ordinates.

Twelve examples are given of plane boundaries, three at obtuse angles, four at right angles and three at 270°.

An Experimental Method of Determining an Irrotational Velocity Field. (W. Barth, Z.A.M.M., Vol. 14, No. 6, December, 1934, pp. 347-348.) (22.0/29923 Germany.)

The boundaries are those of a vessel. The vessel is filled with fine quartz sand with grains of uniform average size and shape taken over sensible elementary volumes. A nozzle with numerous small perforations represents a surface of sources, the sink being the outlet of the vessel.

The passages between the grains are so narrow that laminar flow takes place and the mean resistance coefficient is approximately a linear function of the mean velocity and constant through the volume of the sand. The open end of a thin pipe connected with a gauge is used to explore the pressures. A calibration curve of pressure gradient as a function of mean velocity is given and two isobar diagrams are reproduced.

One reference.

Motion of Stretched String in a Turbulent Flow of Air. (D. Nukiyama, Aer. Res. Inst., Tokyo, Report No. 112 (Vol. 9, No. 4), September, 1934.) (22.0/29924 Japan.)

The author refers to the influence of turbulence, heating by the sun, and wetting by rain, but in forming the differential equations of motion falls back on simplifying assumptions giving the usual linear differential equation with constant coefficients. Formal solutions are developed at some length.

A brief reference is made to physiological scales of intensity. The determination of mean coefficients is not attempted on account of the experimental difficulties.

Sphere Drag Determined by Coasting Through Still Air. (R. T. Sauerwein, J. Aer. Sci., Vol. 1, No. 3, July, 1934, pp. 147-150.) (22.0/29925 U.S.A.)

The apparatus used has been described in a previous abstract (see Abstract 28835). The present paper deals with tests on a 24in. sphere (inflated rubber balloon). Appreciable discrepancies with wind channel results may be due to differences in the turbulence of the air or to the mounting of the sphere. Further investigations are being made.

Four references.

Effect of Bridge Piers on the Resistance of Vessels. (G. Kempff, W.R.H., Vol. 15, No. 19, 1/10/34, pp. 265-268.) (22.0/29926 Germany.)

The effect of increased flow velocity and of standing waves is analysed and the calculated results are in sufficient agreement with measurements to exclude any serious unknown reactions due to eddy formation or otherwise.

Laminar Entry Flow. (H. Schlichting, Z.A.M.M., Vol. 14, No. 6, December, 1934, pp. 368-373.) (22.10/29927 Germany.)

The Blasius differential equation for flow past a semi-infinite plane is extended to flow between two parallel semi-infinite planes by bringing in additional terms.

There is a brief outline only of the analysis and the results are given in numerical tables and graphically for 18 stations intermediate between uniform entry flow and the final parabolic distribution of velocity.

Seven references.

Criteria of Instability of Laminar Flow. (W. Tollmien, Z.A.M.M., Vol. 14, No. 6, December, 1934, pp. 375-376.) (22.15/29928 Germany.)

A brief reference is given to the recent work of H. B. Squire. The resulting differential equation is non-linear. For large Reynolds numbers the problem approaches Rayleigh's treatment and yields his result that there must be no point of inflexion in the curve of velocity distribution.

Oscillations with Quadratic Damping. (W. Müller, Ing. Arch., Vol. 5, No. 4, August, 1934, pp. 306-315.) (22.15/29929 Germany.)

The resistance to the flow of water in a conduit supplied by a reservoir is proportional to the square of the mean velocity under practical conditions. The equation of motion becomes non-linear and the solution is formed by successive approximations up to the third. The numerical results are given in tables and graphs.

Seven references.

The Turbulent "Mixing Length." (H. Gebelein, Z.A.M.M., Vol. 14, No. 6, December, 1934, pp. 357-360.) (22.15/29930 Germany.)

A note on the statistical analogy between molar (turbulent) and molecular exchanges is too brief to touch on the numerous physical difficulties. (Reference is made to a book by the author in the Press, entitled "Turbulence," in which the difficulties no doubt receive fuller discussion.)

It is stated, without proof, that the mean mixing velocity is proportional to the fourth root of the mean vorticity.

Expressions are derived for the "exchange vector" with four simple boundary conditions:—Infinite plane, semi-infinite plane, parallel infinite plane and circular pipe, and are given in tensor notation. The last result is shown graphically.

Oscillations of Ships in a Rough Sea. (G. Weinblum, Z.V.D.I., Vol. 78, No. 47, 24/11/34, pp. 1373-1379.) (22.15/29931 Germany.)

In any given attitude with respect to the wave a ship may undergo linear and angular oscillations which may be related to a system of three axes. The problem may be simplified by considering oscillation with the longitudinal axis parallel or perpendicular to the wave.

The damping of the oscillations has so far been studied mainly for rolling. Attempts have been made to reduce heaving by fitting fins. Irregularities in the waves introduce serious complications and experiments in tanks with artificial waves are required before a general conclusion can be drawn.

The equations of motion can be estimated if the lengths and inclination to the ship of the surface waves is known. Load distribution and moments of inertia are important factors.

Nineteen references.

Equalising Effect of Nozzles on Velocity Distribution. (B. Eck, Ing. Arch., Vol. 5, No. 4, August, 1934, pp. 315-324.) (22.2/29932 Germany.)

The change of velocity distribution by rapid contraction of the nozzle diameter is discussed, with neglect of viscosity, and approximate expressions are obtained.

The experimental values are shown graphically and lie closely on the calculated velocity profile. The experimental apparatus is described and illustrated by a sketch and a photograph.

Flow in Curved Pipes. (M. Adler, Z.A.M.M., Vol. 14, No. 5, October, 1934, pp. 257-275.) (22.2/29933 Germany.)

An approximate solution is constructed for steady laminar flow when the radius of a portion of the pipe is large in relation to the radius of the (circular) cross section.

The velocity distribution in steady laminar flow departs slightly from the parabolic profile with which first and second approximations are compared graphically. At large Reynolds numbers the mathematically intractable problem of turbulent flow is discussed and empirical expressions are constructed. The form of these expressions is, of course, restricted by general principles of dynamical similitude. The expressions in the empirical analysis became very heavy and as there is no unifying physical basis for the methods selected, they are not susceptible of concise abstraction.

The experimental installation is fully described and measured results are plotted and, in some cases, compared with empirical formulæ. Diagrams showing the velocity distribution and the transverse flow are reproduced.

Seventeen references.

Diversion of a Free Jet by a Plane Barrier. (W. Schach, Ing. Arch., Vol. 5, No. 4, August, 1934, pp. 245-259.) (22.35/29934 Germany.)

A summary of two-dimensional theory is given and the free surfaces are shown for six different angles of incidence. Potential and stream functions are shown in accordance with Prandtl's hodographic method.

Experimental results were obtained for jets of rectangular and circular section impinging on a flat plate. The streamlines at the surface of the plate were recorded by lines of flow formed in a thin layer of white paint on the surface of the plate. The pressure of the rectangular jet distribution on the plate was measured directly and was within a few per cent. of the theoretical values.

Twelve references.

Determination of Configuration of Flow in Three Dimensions by the Paint Streak Method. (G. Vogelspohl, Z.V.D.I., Vol. 78, No. 45, 10/11/34, pp. 1332-1333.) (22.36/29935 Germany.)

A boundary surface is covered with a first coat of black lacquer and a second coat of thin white oil paint. The flow of water in the channel etches furrows in the white paint which may be interpreted as mean streamlines in the neighbourhood.

The method is limited to the exhibition of flow near a solid boundary. Examples of flow between the parallel walls of a channel are reproduced. High water speeds are essential and the furrows require 30 seconds or more to form.

Four references.

Method of Calculating Induced Velocity. (I. Tani, Aer. Res. Institute, Tokyo, Report No. 111 (Vol. 9, No. 3), August, 1934.) (22.4/29936 Japan.)

The relation between lift and circulation is expressed by equating total lift to the velocity, multiplied by the integral of the circulation along the span. Various methods of solving the integral equation have been devised.

In the present paper the span is divided into four or five sections, approximate values are assumed and successive approximations converge quickly, and the third approximation is sufficient for all practical purposes. The method of forming the terms is based on Gauss's method of approximate integration.

Four references.

Air Forces on an Elliptic Cylinder in an Ideal Fluid. (A. Ratib, Z.A.M.M., Vol. 14, No. 6, December, 1934, pp. 340-342.) (22.4/29937 Germany.)

The usual expressions for velocity and pressure distribution, resultant force, centre of pressure and moment, are developed, with a view to applications to rudder and aileron control.

Flow Round a Thin Slightly Curved Wing Profile. (F. Weinig, Z.A.M.M., Vol. 14, No. 5, October, 1934, pp. 279-284.) (22.4/29938 Germany.)

In the development in series of the complex expression for streamlines and iso-potentials, the first term gives the simple Joukowsky transformation, approximately to a circle. Higher terms in the series represent flow sources of higher order.

The coefficients of the expansion are obtained from the profile by arithmetical methods.

Irrotational Flow Past a Biplane. (G. Schmitz, Ann. d. Phys., Vol. 21, No. 1, October, 1934, pp. 37-66.) (22.4/29939 Germany.)

Following the original methods of Kutta and applying Joukowsky's criterion of smooth flow at the trailing edges a considerable extension of the analysis is obtained. Lagally obtained the conformal representation of two circles expressed in bi-polar co-ordinates on the inside boundary of a rectangle, the point at infinity becoming the origin in terms of Weierstrasse's elliptic functions. The further step required is the representation of the biplane on the same rectangle.

Expressions are developed for two plane segments, in tandem and superposed, of equal and unequal length by an inverse method. Expansions of the elliptic functions in series give by reversion the required expression.

The resultant lift and moment depend on individual coefficients occurring early in the series and in form resemble closely the expressions for single wing contours obtained by Kutta and Blasius. The pressure distribution over the surfaces is obtained by determining the coefficients of the expansion to higher power.

Approximate numerical values are obtained for a staggered biplane of unequal segments and the pressure distribution is exhibited graphically.

Five references.

Air Flow Past a Heated Sphere. (I. Hartmann, J. Frank. Inst., Vol. 218, No. 5, November, 1934, pp. 593-612.) (22.4/29940 U.S.A.)

A hollow brass sphere of 12.7 cm. diameter was heated electrically to temperatures between 25°C. and 108°. The air resistance was measured in a Venturi type wind channel of 8.4 m.^{2} sectional area, at air speeds from 27 to 160 m. per sec., giving Reynolds numbers from 70,000-210,000.

Measurements were made with and without a wire gauze screen in front of the sphere.

Tables of experimental data are given and results are also shown graphically.

Five references.

Reaction Diffusor. (J. Chalom, Comptes Rendus, Vol. 199, No. 23, 3/12/34, pp. 1289-1291.) (22.5/29941 France.)

The general arrangement of jet and diffusor is shown in a sketch and dimensions are given from experimental investigations.

Expressions are written down for the reactions at a fixed point and in uniform motion through the air.

Computation of Two-Dimensional Flow in a Laminar Boundary Layer. (H. L. Dryden, N.A.C.A. Report No. 497, 1934.) (22.6/29942 U.S.A.)

From Author's Abstract.—A comparison is made of the boundary layer flow computed by the approximate method developed by K. Pohlhausen with the exact solutions which have been published for several special cases. A modification of Pohlhausen's method has been developed, which extends the range of application at the expense of some decrease in the accuracy of the approximation.

Seven references.

Materials, Elasticity and Plasticity

A General Property of Two-Dimensional Thermal Stress Distribution. (M. A. Biot, Phil. Mag., Vol. 19, No. 127, March, 1935, pp. 540-549.) (23.10/29943 Great Britain.)

The thermo elastic equations are written down and two conditions for zero stress with steady temperature distribution are deduced in terms of elastic constants and strains only.

The cubic thermal expansion, and hence the (steady) temperature field, satisfies Laplace's equation. The remaining condition is a relation between Young's modulus, the cubical thermal expansion and the axial stress only. It follows that a uniformly heated cylinder expands freely in the plane of each right section.

For a hollow cylinder the total flows over each (inner and outer) surface must be zero and two contour integrals round each boundary must be zero. In an example an analogy with the theory of elastic dislocations is shown, which suggests a method of applying stress optical observations to thermal problems.

One reference.

Magnetic Fault Detection. (Flight, Vol. 27, No. 1367, 7/3/35, p. 248.) (23.10/29944 Great Britain.)

In " Bristol " works inspection, a magnetic flux is passed through the test article and a liquid with suspended iron particles is applied to the surface. A concealed fault produces variation in the flux density which is indicated by local concentrations of the iron particles.

Rivet in Plate of Finite Breadth. (R. C. Knight, Phil. Mag., Vol. 19, No. 127, March, 1935, pp. 517-540.) (23.10/29945 Great Britain.)

The elastic equations are written down in polar co-ordinates for Filon's conditions of generalised plane stress. The stress function is built up by superposing partial stress function, satisfying successive conditions.

Selection is made of suitable expansions for these functions in series and the coefficients are determined to satisfy the boundary conditions of the various problems. The stresses due to the stress function are then computed and tabulated. The effects of changes in the generalised Poisson's ratio are discussed.

The paper is an extension of previous work by other authors, to whom full references are given.

Eight references.

A New Form of Solution of Problems in Elasticity. (H. Neuber, Z.A.M.M., Vol. 14, No. 4, August, 1934, pp. 203-212.) (23.10/29946 Germany.)

The elastic stress-strain equations are transformed by the introduction of three harmonic functions to a form which expresses the displacements by differentiation of the stress function.

The appropriate functions are given for torsion of a prismatic rod in cartesian co-ordinates and for a circular cylinder in polar co-ordinates.

Rules for transformation to curvilinear co-ordinates are given and the method is applied to a hollow cone.

Eleven references.

Photo-Elastic Measurements in Aircraft Construction. (M. V. Tesar, Tech. Aéron., No. 134, pp. 213-225, and No. 135, 1934, pp. 159-176.) (23.15/29947 France.)

The usual types of photo-elastic patterns are reproduced. Celluloid test pieces are attached to engine parts and follow their deflections. The strains in the attached test pieces are recorded through a cycle by a high speed cinematograph.

Reference is made to the work of Tuzi and others (Sci. Papers of Inst. of Phys. and Chem. Research, Tokyo, 1928).

Four references.

Coefficient of Photo-Elastic Extinction. (J. Kuno, Phil. Mag., Vol. 19, No. 126, February, 1935 (Suppmt.), pp. 457-466.) (23.15/29948 Great Britain.)

Certain precautions are required in calibrating specimens of phenolite for photo-elastic experiments.

A rapid method of calibration is described which eliminates the effect of initial stresses and of creep.

Three references.

Tests on Aluminium Alloy Sheet. (C. G. Brown and S. R. Carpenter, Air Corps Inf. Circ., Vol. 7, No. 691, 10/7/34.) (23.20/29949 U.S.A.)

Thirteen tables of data are given for permissible bearing values of rivet pins in heat treated aluminium alloy sheet of standard U.S.A. specifications.

The allowable bearing stress with 4 per cent. elongation of transverse diameter of pin was found to be constant, irrespective of diameter in the range 3/32 inch to 3/16 inch and of sheet thickness in the range 0.015 inches to 0.05 inches.

The average permissible bearing stress varies from 75,000lb. per sq. inch to 90,000lb. per sq. inch, according to the specification of the alloy sheet.

Strains and Stresses in Thin Circular Rings and Pipes. (M. J. Gercke, Z.A.M.M., Vol. 14, No. 5, October, 1934, pp. 313-315.) (23.30/29950 Germany.)

The approximate differential equation of elastic stability for the assumed boundary conditions is linear of the fourth order and has constant coefficients.

The solution is obtained in the usual way in terms of elementary functions and this in turn is transformed to a convergent series, three terms of which give a sufficient approximation.

Buckling of Vertical Rods Under Their Own Weight. (A. Leon and E. Erlinger, Ann. d. Phys., Vol. 20, No. 6, September, 1934, pp. 635-645.) (23.30/29951 Germany.)

Greenhill's formula is applied numerically to the buckling area of circular sections of iron, steel, copper, aluminium and lead. Static and dynamic methods

of experimental determination give continuous series of equilibrium positions with continuously increasing lengths beyond the critical value.

Greenhill's results correspond to particular cases in these series, but give a fair mean value with − 4 per cent. and + 7½ per cent. of the extreme experimental cases. Time creep in aluminium wire shows a series of instantaneous equilibrium positions.

Nine references.

The Strength of Metal Pipes Under Internal Pressure. (E. Siebel and E. Kopf, Z. Metallk., Vol. 26, No. 8, August, 1934, p. 169.) (23.30/29952 Germany.)

The flow of metal from yield point up to final rupture was observed in tubes of carbon steel, lautal, copper, brass and lead, under tension and under internal pressure.

The non-ferrous metals were inferior to steel under internal pressure; the inferiority was less marked under tension.

Two references.

Breaking Tests of Flat Struts of Variable Widths. (H. Fromm, Z.A.M.M., Vol. 14, No. 6, December, 1934, pp. 353-357.) (23.30/29953 Germany.)

Elementary generalities are given on stress distribution in round and flat struts.

Breaking tests on flat struts with constraint preventing lateral bending show failure in shear or in tension—according to the material. In some cases a tensile failure at the centre passes into a shear failure in the outer layers.

The numerical values from experiment are difficult to reconcile with the approximate theory.

Eleven references.

Transverse Oscillations of Beams Under Moving Variable Loads. (A. N. Lowman, Phil. Mag., Vol. 19, No. 127, March, 1935, pp. 708-715.) (23.30/29954 Great Britain.)

Reference is made to existing solutions for uniform velocities, and to a method of successive approximations for variable velocities.

A rigorous formal solution is obtained for the general problem of variable loads and velocities. No numerical results are worked out.

Five references.

Strength of Structure. (C. Minelli, L'Aerotecnica, Vol. 14, Nos. 8/9, August/September, 1934, pp. 991-1029.) (23.40/29955 Italy.)

Elementary examples are given, with sketches, of deformation of structure and failure by local buckling of struts and flanges. Experimental work on buckling of thin flanges is shown in over twenty photographs.

Comparison is made with Southwell's theory of buckling. The discussion is non-mathematical.

Forty-eight references.

Stressed Skin Construction. (E. E. Blount, J. Aer. Sci., Vol. 1, No. 4, October, 1934, pp. 186-194.) (23.41/29956 U.S.A.)

A descriptive account is given of the numerous problems of detail entering into the design of structures in which the covering carries some part of various stresses.

Illustrative numerical values are given throughout and rules for design are stated. Types of metal spare ribs and covering are shown in seven sketches.

Two references.

Matrices Applied to Motion of Damped Elastic Systems. (W. J. Duncan and A. R. Collar, Phil. Mag., Vol. 19, No. 125, February, 1935, pp. 197-219.) (23.46/29957 Great Britain.)

A previous paper dealt with undamped systems.

In the present paper damping forces are introduced. The differential equations are in both cases linear, with constant coefficients. A matrix notation is defined and several relevant properties are established. The method is a purely numerical one and depends on successive substitution. Numerical examples are fully worked out in both papers.

Three references.

Natural Modes of an Equilateral Triangular Membrane. (L. Collatz, Z.A.M.M., Vol. 14, No. 5, October, 1934, pp. 315-317.) (23.46/29958 Germany.)

The methods of finite differences are applied. The triangle is sub-divided by a network of regular hexagons, the nature of the potential function at a vertex being one-third of the sum of the values at the three neighbouring vertices.

A numerical example is worked out and the nodal lines of the first ten periods are shown graphically.

Two references.

Oscillation of Systems with Two Degrees of Freedom. (W. Quade, Z.A.M.M., Vol. 14, No. 6, December, 1934, pp. 365-366.) (23.46/29959 Germany.)

The roots of the usual quartic for the period are classified and fourteen possible combinations are obtained from changes of sign and from the presence of complex conjugate roots and of multiple roots.

The Vibration of Steam Turbine Blades. (K. Karas, Ing. Arch., Vol. 5, No. 5, October, 1934, pp. 325-352.) (23.46/29960 Germany.)

The general differential equation is formed for blade vibration in the plane of rotation, taking into account centrifugal action.

An example is worked out numerically, the result being in fair agreement with experimental values.

Forty references.

Miscellaneous

Locomotives with Condensers. (Z.V.D.I., Vol. 78, No. 40, 6/10/34, pp. 1171-1172.) (29961 Germany.)

Messrs. Henschel and Son have developed a surface condenser incorporated in a special tender which can be attached to existing locomotives, after minor modifications. The water consumption is very considerably reduced, 10 tons sufficing now for a run of over 500 miles. Installations are working successfully in Russia and the Argentine.

Burlington Zephyr. (E. C. Anderson, Trans. A.S.M.E., Vol. 56, No. 9, September, 1934, pp. 659-666.) (29962 U.S.A.)

Author's Abstract.—The Chicago, Burlington and Quincy Railroad Company's " Zephyr " comprises three cars supported on four roller-bearing trucks, with articulated joints between adjacent cars. Its load-carrying truss members are of 18-8 stainless steel, as is also its unpainted outside surface. Its roof and belly sheets, and also its steel floor, share in the work of carrying load. All truss members and other stainless steel parts are tied together by the " shot-weld " system, in which a specialised and improved form of spot welding is used under such exact control of pressure, current, and time that the welds do not adversely affect the non-corrosion qualities of metal or joints.

The motive power is furnished by a 660 h.p. two-cycle Diesel engine driving a generator which produces current for the two traction motors which are mounted on the axles of the front truck. The train is streamlined and smoothed throughout its entire length to reduce air resistance, has automatically controlled steam heat, air conditioning and cooling, and electric buffet service and lighting.

The " Zephyr " has broken all records for long-distance runs, both as to mileage and speed, having made a non-stop run from Denver to Chicago, 1,015 miles, in 13 hrs. and 5 min. Much of this run was at speeds in excess of 100 m.p.h.

Different Types of Coupling in the Frahm Anti-Rolling Tank. (O. Föppl, W.R.H., Vol. 15, No. 24, 15/12/34, pp. 357-358.) (29963 Germany.)

A descriptive account is given of the physical factors entering into the problem and a partial differential equation is quoted from a previous paper, the terms and coefficients of which illustrate the descriptive remarks.

Three references.

The Mechanics of Caterpillar Tractors. (E. Heidebrock, Z.V.D.I., Vol. 78, No. 43, 27/10/34, pp. 1276-1280.) (29964 Germany.)

Elementary principles are discussed. Turning is best effected by having separate electric drives on each band. Differential gears are described as an alternative.

The Motor Car in the Service of the Army. (W. Xylander, Z.V.D.I., Vol. 78, No. 43, 27/10/34, pp. 1249-1252.) (29965 Germany.)

In previous wars operations were largely conditioned by facilities for railway transport of men and materials. The motor car renders operations less dependent on the railway system and increased mobility may make up for inferior numbers.

The armoured car or " tank " as a weapon of attack should not be overrated in view of improvements in anti-tank weapons.

Nine photographs of French and British tanks and caterpillar tractors are given.

Two references.

Fire Tactics of Fighter Formations and Light Bombing Formations. Translated from the Russian. (Riv. Aeron., Vol. 10, No. 10, October, 1934, pp. 97-136.) (29966 Italy.)

Thirty diagrams illustrate problems of fire control arising out of attacks by fighter formations on light bombing formations.

Visit of Soviet Military Mission to France. (L'Aéron., No. 186, November, 1934, p. 280.) (29967 France.)

A visit to Paris has been made by three Russian low wing four-engined bombers. The water-cooled wing engines rated at 600 h.p. each are of Russian manufacture. Ten photographs show details of the machines.

According to the author the general design follows closely that of Junkers and is about four years behind modern practice.

REVIEWS

Max Immelman

By Franz Immelman, translated by Claud W. Sykes. Published by John Hamilton, Ltd. Price 8/6.

This book is a life of the well-known German " ace," written by his brother, who was also a fighting pilot. In the original German it is probably a well written book, but the translation does not inspire enthusiasm; there are signs everywhere that Mr. Sykes hardly understands enough about aviation to appreciate the descriptions.

Immelman had, apparently, some fifteen or sixteen recorded victories and seems to have acquired about the same number of decorations. He was the first fighting pilot in the war to become notable for his achievements. His personal qualities fitted him for his task. He was an excellent shot, cunning in attack, and an excellent pilot, and he deserved thoroughly the fame that came to him. He was fortunate in having at his disposal an excellent fighting machine well suited to his fighting temperament, and he made good use of it against opponents using an inferior equipment. He was killed eventually during a fight, according to this book, owing to the collapse of his machine brought about by severe vibration following the loss of a propeller blade, which is said to have been shot off by his own gun. The account of his death is given with a wealth of detail, though how this could have been seen by his colleagues who were, at the time, busily engaged in fighting, is not explained. In the " War in the Air " he is stated to have been shot down by McCudden.

Had this book been translated by a fighting pilot with a knowledge of writing it would have been well worth reading.

Relativity

Dr. F. W. Lanchester, LL.D., F.R.S., F.R.Ae.S.(Hon.). Published by Constable and Co., Ltd. Price 12/-.

Dr. F. W. Lanchester is an important aeronautical personage. His early work on the flow of air round aerofoils and other bodies was notable, not only for its originality, but also because it laid the foundation for modern aerodynamical theory on which all experimental work is based. He is an Honorary Fellow of the Society and holds the Gold Medal, the highest honour which the Society has the power to bestow.

He has attempted in this book to present the theory of relativity, and the modern views concerning the relations of space, time and gravitation in the simplest possible language. It is difficult to be sure whether he has succeeded because the book is, possibly unavoidably, distinctly heavy reading in many places, but the author certainly seems to have done his best to explain the unexplainable. The fundamental starting point concerns the fact that the velocity of light is an absolute physical constant, a fact which can be demonstrated experimentally. For instance, if one were to measure the speed of light while stationary and then to measure it again while proceeding along the beam in either direction at a speed of, say, 60 miles an hour, the result would be the same in all three cases, the speed of the observer having not the slightest effect on the result, which seems to be always a constant.

This fact when grafted on to space of cosmic proportions leads to very curious happenings in which time variations are concerned with relative velocity and even lengths vary under different conditions. But not content with this, the mathematicians have adopted a type of space called Riemannian to which are assigned properties which are inconceivable, though to some extent its shape appears to be related to that of a simple sphere. Among other attributes it has no boundaries, but is, at the same time, limited in volume. It is not even clear, as Dr. Lanchester remarks, whether it has an inside and an outside, or several of each, or even whether it has a concave or convex aspect. The author surely is justified in remarking that there seems to be a tendency to express the cosmos in mathematical terms, although the explanation may be more incredibly fantastic and complicated than that which is to be explained.

The book should be read by all who wish to keep in touch with modern thought. The prose is as lucid as the subject permits and the author has illuminated it in many places by his common-sense way of looking at things and his frank criticism of unsound propositions. Dr. Lanchester has the type of mind which can make the fundamental and clarifying discovery in light of which all the known facts fall into order. It is to be hoped that he will do for relativity what he has already done for aeronautics.

Aeroplane Structures

By Professor A. J. Sutton Pippard, D.Sc., and Captain J. Laurence Pritchard. Longmans, Green and Co. Price 21/-.

This book is the second edition of a work originally published in 1919, and in the intervening sixteen years there has been much progress in construction and in calculation. In 1919 the usual constructional material was wood, and the usual aeroplane was a biplane, while to-day metal construction is almost universal in large aircraft and the direction of design is tending strongly towards monoplanes. Hence it follows that many stress problems of great importance to-day were not even propounded in 1919.

It is probable that no one book on aeroplane design was more universally used and studied than the original edition of this work. Both the authors had had considerable practical experience of the difficulties which were likely to be encountered in aeroplane stress work and they possessed a knack of clear and lucid explanation which made the book particularly easy to understand. When some unusually knotty problem was encountered, Aeroplane Structures could be relied on to produce, if not the answer itself, at least the key from which the answer could be ascertained.

It is enough to say that the second edition is a worthy descendent of the original. Although the book has been practically re-written, much of the fundamental matter retains nearly its original form, and the chief difference between this edition and the first consists in the additions. Strain energy methods are now given a chapter to themselves and special attention is given to the theories of Castigliano and certain papers by Professors Southwell and Pippard, which latter describe ways of simplifying actual design, which under the normal strain energy procedure was a long and complicated process if more than one or two redundant members were concerned. Thin metal construction has a chapter to itself, in which the difficulties concerned with this matter are dealt with adequately, as far as it is possible to analyse them mathematically in a book of this nature. The method devised by H. B. Howard for the graphical solution of problems connected with end-loaded beams is dealt with in its appropriate chapter, and the modification to the theory of these moments to enable it to deal even more closely with spar problems is given. Only in one case does the treatment seem inadequate and that is in connection with problems of stiffness in torque such as occur with the wings of cantilever monoplanes, though the basis of this subject

is dealt with in a special chapter where the main principles are given and also the various ways in which flexibility of structure may lead to trouble.

Generally, the book is admirable and it should be the standard textbook on its subject for many years to come.

Visibility in Meteorology

By W. E. Knowles Middleton, M.Sc. Published by the University of Toronto Press. $2.

Visibility in flight is a matter of great and increasing importance to the operation of aircraft, and this book, which deals with the matter scientifically, has appeared at an appropriate moment. It contains a great deal of very pertinent information, an adequate bibliography, a description of certain special instruments for the purposes of measurement, and a mathematical discussion of the whole subject.

There is no doubt that methods of indicating to aircraft pilots the degree of visibility they may expect to find at some future period of the flight, require overhauling. As the author points out, the visibility of an object is the ease or the extent to which it can be seen. Actually it is interpreted in practice as a distance at which some alleged prominent object cannot be seen. As the visual range of any object is dependent on many of its properties as well as on the atmospheric conditions, another disturbing element is introduced which may and does lead to estimates of visibility from different stations being totally discordant.

The whole question is further complicated by the necessity of estimating visibility at night and when the results are available there is the difficulty of transferring to the aeroplane pilot a picture of what he may expect to find when, let us say, he desires to land.

Mr. Middleton makes many useful and important suggestions on the solving of these difficulties, and it would appear to be very advisable that the methods he suggests should be tried out in practice, and that at important aerodromes special instruments should be installed for the purpose of taking accurate readings. The matter should no longer be left to the approximate methods of the past.

The 590th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

A meeting of the Society was held in the Lecture Theatre of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2, on Friday, March 1st, 1935, when a paper on "Fuels for Aircraft Engines," by Mr. E. L. Bass, was read and discussed. In the chair, the President (Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S.).

The CHAIRMAN: Mr. Bass had devoted his life to research in connection with fuels for internal combustion engines. He had been attached to the Shell group since 1919, and seven years of his time had been spent in fuel experimental work in conjunction with Mr. Ricardo. Since then he had become Chief Engineer of the Shell Aviation Department of the Asiatic Petroleum Company.

FUELS FOR AIRCRAFT ENGINES

BY

E. L. BASS, A.F.R.Ae.S., M.I.A.E., M.I.Ae.S., M.S.A.E.

It is unnecessary to enlarge on the importance of the fuels used in aviation in a paper before this Society. Not only is fuel quality the most important individual factor to be considered in the economics of civil aviation, but engine development, aircraft design and performance depend upon it.[1]

An apology is offered, in view of the title of the paper, that as it is barely possible in the confines of a single paper to deal adequately with the volatile fuels (known as petrols and gasolines) used in the normal carburettor or homogeneous charge engines, other types of fuels have necessarily been omitted. Compression ignition engine fuels and the so-called "safety fuels" are used only in extremely small quantities in relation to the quantity of gasoline used in aviation at the present time. It is difficult to forecast how long this position is likely to obtain, for with each step forward in the development of the compression ignition engine a similar step seems to be made by the gasoline engine. Just when a halt will be called in the progress of the gasoline engine will depend upon the development of the fuels it requires. It is a most significant fact, however, that whereas future development of the gasoline engine can only be gained at the cost of fuels technically more difficult to produce and therefore more expensive, the development of the compression ignition engine will steadily make it less selective in its fuel requirements, to its economic advantage.

The fuel requirements of gasoline engines vary not only with the type of engine but with the service in which they are employed. By far the most fastidious in its fuel tastes is the aircraft engine.

Although the following notes will be found to contain much that is common knowledge on the subject, it is hoped that the general summary attempted will be of use and that some of the experimental work that has been carried out will ultimately prove of practical value.

The various fuel characteristics have been dealt with in the subsequent sections of the paper. These have not been put in any order of importance since, there being few compromises possible, a satisfactory aviation fuel can only be one which meets completely every requirement.

[1] See Appendix No. 1.

Anti-Knock Value

The property possessed by fuels of resisting detonation was originally investigated by Mr. H. R. Ricardo in 1919.[2] Until this research had been carried out the phenomenon of detonation in gasoline engines was very imperfectly understood and many engine failures doubtless due to detonation were frequently ascribed to other causes.

It may be as well briefly to examine the known practical effects and influence of detonation—the theoretical study of the subject being quite outside the scope of this paper.[3] For his original work, Mr. Ricardo designed the now famous E.35 variable compression engine. The important feature of this engine is that the compression ratio can be varied whilst the engine is running, the range being from 3.5 to 8.0 : 1. Thus the variations in performance can readily be observed with changing compression ratio, other conditions remaining constant. Fig. 1

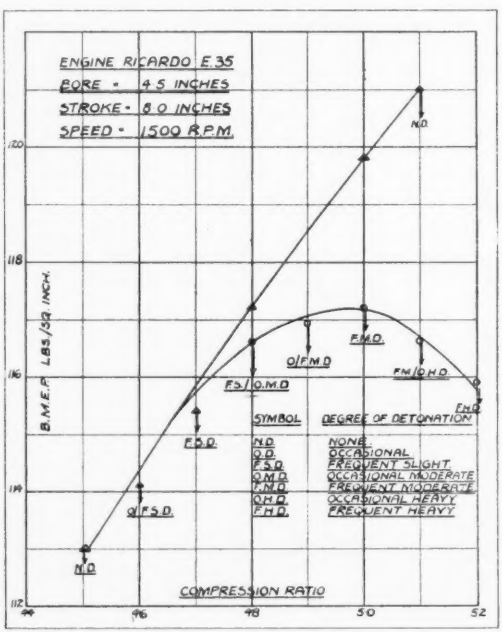

FIG. 1.

shows two B.M.E.P./compression ratio curves, one obtained with a fuel on which detonation was absent at all compression ratios and the other with a fuel on which detonation became so severe that power output diminished as the compression ratio was increased above 5.0 : 1. Since the speed of revolution and the gross fuel consumption of the engine remained constant it is obvious that when detonation induces a loss of power the balance of the heat energy of the fuel is liberated in ways other than in useful work, the actual amount of heat energy thus wasted being a function of the degree of detonation. These additional heat losses will be considered later, but it is sufficient to say that under certain circumstances they can lead to complete engine failure. The usual sequence of events is that the

[2] Report of the Empire Motor Fuels Committee, Proc. I.A.E., Vol. XVIII, Part 1.
[3] See work of Egerton, Dixon and others.

increased heat flow to the piston causes rapid carbonisation of the lubricating oil in the piston ring grooves, with the result that the rings stick. Blow-piping of the gases past the piston follows, which rapidly leads to complete burning of the side of the piston. Occasionally, with severe detonation, piston crowns collapse in the centre with the high temperature to which they are subjected, whilst burning of the cylinder head is also possible. Valve seat inserts may also become

FIG. 2.

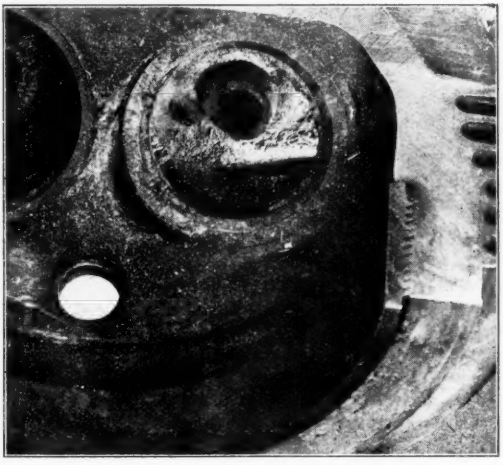

FIG. 3.

loosened under detonating conditions and this again may lead to serious mechanical failures.

In Figs. 2, 3 and 4 typical effects of detonation are shown after running an experimental engine on a very low anti-knock value fuel with the express purpose of inducing failures of this nature. Fig. 2 shows a piston with which detonation has progressed to the extent of burning the top land and subsequently destroying

the rings and the whole piston seal. Fig. 3 shows a sectioned cylinder in which detonation has caused failure by burning away the head behind the valve seats.

Due to the pressure and temperature conditions obtaining, aluminium surfaces in the combustion chamber usually show unmistakable signs of detonation by complete lack of carbon formation and a roughened or pitted appearance, the eutectic probably being removed. A typical example is shown in Fig. 4. The rapidity with which the effects of detonation become manifest obviously will depend upon its severity and the length of time it persists. The degree of detonation which is assumed to occur in aircraft engines is, as a rule, insufficient to cause any measurable loss in power, from which it might be reasoned that such detonation is unharmful. Experimental evidence, however, indicates that under such conditions of detonation there is a re-arrangement of the waste heat balance, some of the heat normally passing out in the exhaust gases being given up to the piston and cylinder head, which are the places at which it is most likely to

FIG. 4.

cause trouble. If only slight detonation occurs at infrequent intervals (as, for instance, during take-off and climb) the temperature rise may only be sufficient to cause piston ring sticking by a gradual accumulation of carbonised oil after a comparatively long period of running. The time factor in this case is long enough for the actual cause of the trouble to be extremely obscure and probably the only way of finding it is a prolonged test under similar flying conditions on a fuel of higher anti-knock value. Thus an engine capable of running 200/300 hours between overhauls on its designed fuel, may have that period extended to 500/600 hours by a suitable change of fuel.

It appears logical, therefore, that detonation should be avoided under all running conditions if a satisfactory factor of safety is to be preserved. On the other hand, it is known that most engines are designed so that under take-off conditions a certain degree of detonation is present and permitted. It is thought, however, that the conditions laid down in the detonation test of the Air Ministry type test[4] are adequate to ensure that an engine which passes it will not suffer any ill effects from detonation in service. Whether this assumption is justified or not is open to some question, particularly with modern supercharged units for reasons which are given later. In any event, the comparatively short duration of the detonation test and the fact that it takes place at the end of the

[4] Airworthiness Handbook for Civil Aircraft—Air Publication 1208—Design Leaflet C2, para. 52, and Design Leaflet C3, para. 9 (iii). See also Appendix No. 2.

complete type test may not be sufficient to show up the delayed effects of slight detonation which may come to light under commercial service conditions.

Whatever degree of detonation may be considered tenable, or whether it must be avoided altogether, there are two fundamental problems introduced, viz. :—

(1) A means of detecting detonation in full-scale aircraft engines.
(2) The determination of the relative anti-knock values of fuels under laboratory conditions which will give results in the same order as would be obtained on a full-scale engine.

Of these, the second problem has been examined by the Sub-Committee on Knock-Rating of Aviation Fuels of the Institution of Petroleum Technologists. A full report on the work carried out was presented by Mr. D. R. Pye (who was Chairman of the I.P.T. Committee) at the World Petroleum Congress in 1933.[5] The tests embraced the determination of the knock-ratings of a number of different fuels against a sub-standard reference fuel on a variety of single-cylinder aircraft engines. A means of running the C.F.R. engine was then determined which would give results to correlate satisfactorily with those obtained on the aircraft engine tests. Thus the " modified motor method "[6] of operating the C.F.R. engine came into being and it was immediately adopted by the British Air Ministry in its Fuel Specifications, Nos. D.T.D. 224 and D.T.D. 230.[7]

It occasioned some surprise that the I.P.T. tests should show that correlation with the single-cylinder engines working under supercharged conditions could be obtained by a less severe method of running the C.F.R. engine than the " motor method " for automobile engines, the difference in results obtained by the two methods amounting to one to two octane numbers. At first sight it appeared that the high cylinder temperatures, higher B.M.E.P.'s and volumetric efficiencies of aircraft engines would induce greater tendency to detonation and deterioration of the knock-rating of gasolines than automobile engines. Future investigations may prove this supposition to be correct, but at the moment there is little reliable evidence to support it. Additional criticism has been levelled at the I.P.T. tests on account of the fact that the aircraft engine tests were made on single-cylinder units using only aural methods for the detection of detonation. The influence of American practice is clearly present in this criticism, as in America only full-scale multi-cylinder engine tests and detonation observations made by cylinder temperature measurements are acceptable. It is hoped that the present series of I.P.T. tests will enable all these criticisms to be answered.

Shortly after the acceptance by the British Air Ministry of the " modified motor method " as the official method for testing aviation fuels, the American Society for Testing Materials (A.S.T.M.) made the " motor method " the standard method in America. This was purely a tentative arrangement, however, pending the completion of an elaborate series of knock-rating correlation tests to be conducted on full-scale multi-cylinder engines. Preliminary results only of these tests are available so far, but it is said that these indicate that " . . . any changes in the C.F.R. motor method as applied to rating fuels for aircraft spark ignition engines should not be in the direction of decreased severity."[8] The method employed for rating fuels in the full-scale engines used for these tests is of considerable interest and is referred to on page 895.

Although all the correlation tests made to date have necessarily involved some means of detecting and judging the intensity of detonation on full-scale cylinders, it is this aspect of the whole fuel problem which introduces the greatest difficulties and probably the largest sources of error as well.

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[5] The Knock-Rating of Aviation Fuels, by D. R. Pye, Proc. World Petroleum Congress, London, 1933, Vol. II. See also Appendix No. 3.
[6] See Appendix No. 3.
[7] See Appendix No. 5.
[8] Correlation of Knock-Rating of Aviation Gasolines, by Arthur Nutt, S.A.E. Journal.

On most single-cylinder engines, it takes but little experience to be able to pick out the sound of detonation when it occurs. To judge intensity of sound for comparative test purposes is altogether more difficult although it can be conceded that skilful operators are capable of doing this satisfactorily. Even so, there still remains the difficulty that intensity of sound of detonation is not related to the degree of detonation in the same way for all fuels, whilst in some engines the relation is considerably affected by atmospheric conditions for which it is difficult to apply a correction. In any event, it is not the noise made by detonation which causes engine troubles, however objectionable it may be to a sensitive ear, and unless a reliable relation between the sound and effects of detonation can be established there is little to commend the measurement of detonation by sound alone. In the case of full-scale multi-cylinder aircraft engines, it is generally impossible to hear detonation at all owing to the magnitude of mechanical, exhaust, propeller or cooling air noises.

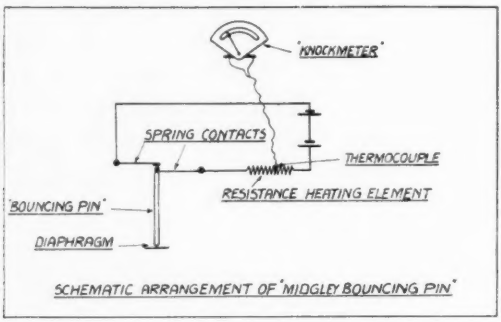


FIG. 5.

The need for a means of measuring detonation accurately was felt acutely in the early days of fuel testing and the Midgley bouncing pin was developed to satisfy this need. A diagrammatic arrangement of this apparatus is shown in Fig. 5 from which it will be seen that it relies for its operation upon the deflection of a diaphragm which is placed in direct communication with the combustion chamber. Thus variations in maximum pressures (which, as will be shown later, vary with the degree of detonation) are recorded on a purely arbitrary scale on the "knock meter." The application of the Midgley bouncing pin has been almost entirely restricted to fuel testing engines, there being some uncertainty as to its suitability for engines of over 3½in. bore or those running at speeds in excess of 1,200 r.p.m.

Recourse has to be made to other means of detecting detonation on full-scale engines, and a recapitulation of the various methods employed is of interest.

(*a*) *Occurrence of Exhaust Smoke*

One of the earliest and still used[9] means of observing detonation is by the occurrence of puffs of black smoke in the exhaust. These puffs are occasional, but quite unmistakable. Whilst there is no possible doubt but that detonation is present when these puffs appear, it is considered to be an unreliable method since it depends so much on the types of engines and fuels used.

Further, it is generally necessary to reach a very advanced stage of detonation before black smoke appears in the exhaust. There must be, therefore,

[9] Neuere Deutsche Untersuchungen über verbrennung und klopfen mit einem bericht über klopfmessungen in Flugmotor, by Dr. von Philippovich, Proc. World Petroleum Congress, 1933.

a quite considerable range of detonation occurring before it is actually recorded. This may lead to the rating of an engine on a given fuel at a power at which detonation will always be present. The possibility of this is perhaps remote, as it is probable that a type test will show up any effects of detonation, but there is certainly some danger if this method is employed for the determination of the suitability of fuels for a certain engine if only short tests are made.

A further complication is added by the fact that the commencement of detonation does not occur at the same time in relation to heavy detonation with all fuels, as shown in Fig. 6.

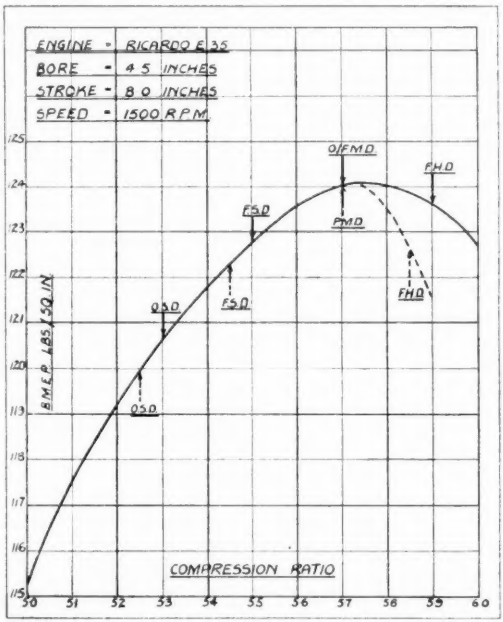


FIG. 6.

For modern aircraft engines, manufactured with such precision and accuracy of inspection and testing, it is clear that far greater accuracy is necessary in the methods employed for the detection of detonation than is provided by the inspection of exhaust gases for occurrence of black smoke.

(*b*) *Appearance of Exhaust Flame*

Under conditions of no detonation with approximately maximum power mixture strength, the exhaust flame as it issues from the port is chiefly blue in colour with only occasional splashes of yellow and orange. With the occurrence of detonation, the appearance of the yellow flame is more marked and frequent. It is probable that a practised observer can detect quite early stages of detonation by this means.

Without the necessary experience and skill, however, the method is likely to be extremely misleading on account of the sensitivity of exhaust gas colour to mixture strength. Consequently, in multi-cylinder engines in which perfect distribution of fuel in the mixture and of the mixture itself cannot always be

maintained, variations in flame colour will occur due to mixture strength effects which may readily be confused with the effects of detonation. The examination of exhaust flame colour cannot, therefore, be regarded as a scientific or accurate means of detecting detonation.

(*c*) *Measurement of Power Output*

It has been seen in Fig. 1 that with increasing compression ratio on a given fuel, the power output falls off after a certain degree of detonation is reached. This phenomenon may be utilised in various ways for the detection of detonation in full-scale engines, *e.g.*:—

(1) The B.M.E.P. at full throttle and constant revolutions may be recorded for a range of fuels of varying anti-knock value. The curve in Fig. 7 shows typical results obtained on such a test. The curve becomes asymptotic with the fuel of anti-knock value at which detonation is absent.

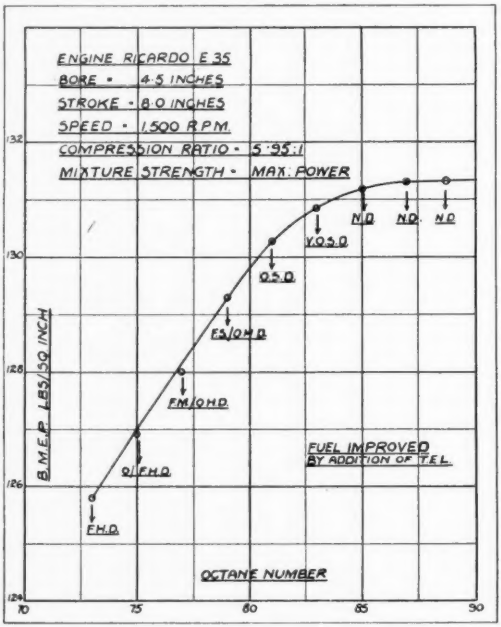


FIG. 7.

(2) By reducing engine speed, but maintaining maximum torque (*i.e.*, running at full throttle) the tendency to detonation is increased. In some engines this is due, to a small extent, to the higher volumetric efficiency obtained at the lower speed. There seems little doubt, however, but that the effect is chiefly due to the longer time factor during which combustion takes place.

The extent to which engine speed may be reduced without detonation obviously is dependent upon the anti-knock value of the fuel. It can be safely assumed that a given fuel is suitable for an engine providing detonation only occurs at a speed of revolution on the B.H.P./r.p.m. curve which shows a power output in excess of that read from the propeller curve. (With variable pitch propellers, the coarse pitch curve must be considered.) To ascertain this

it is necessary to make comparative tests on the fuel to be examined and a fuel of appreciably higher anti-knock value than it is known the engine requires for normal running. The latter fuel should enable a power output (B.H.P./r.p.m.) curve to be plotted down to comparatively low speeds without detonation. If detonation occurs on the test fuel, the B.H.P. curve obtained on it will fall away from that of the higher anti-knock value fuel, as shown in Fig. 8. The point of intersection of the two curves occurs at the r.p.m. at which detonation is just absent; at any rate, the intensity is insufficient to affect power output. Providing that, as already stated, at this speed the B.H.P. is greater than that read from the propeller curve, the test fuel would be judged satisfactory.

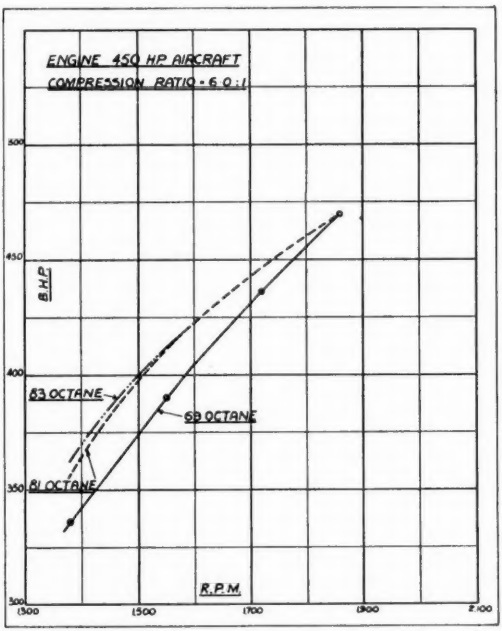


FIG. 8.

(3) Apart from mechanical considerations, the limit to which engines may be supercharged is set by the anti-knock value of the fuel. The effective anti-knock value of an unknown fuel can be determined in a supercharged engine in comparison with that of a fuel of known characteristics. General experience has shown that the onset of even slight detonation in supercharged engines quickly leads to severe detonation and pre-ignition with consequent loss of power. Thus comparisons only can be made using fuels of known suitability for the test engine as standards.

For general practical purposes the methods described above are reasonably satisfactory and may be considered in conjunction with the methods adopted on the single-cylinder engines used for the I.P.T. tests.[10] Such tests can only be made on a test bench with the engine coupled to a suitable dynamometer and are subject at least to the experimental errors common to tests made under those conditions.

[10] See Appendix No. 3.

(d) Measurement of Heat Losses

It has already been shown that with the occurrence of detonation the heat losses are increased. A large proportion of these are transmitted through the cylinder and head walls to the cooling medium. With liquid-cooled engines the heat rejected to the liquid can be accurately measured in the engine laboratory. Monsieur Champsaur[11] of the Service Technique de l'Aéronautique has made a

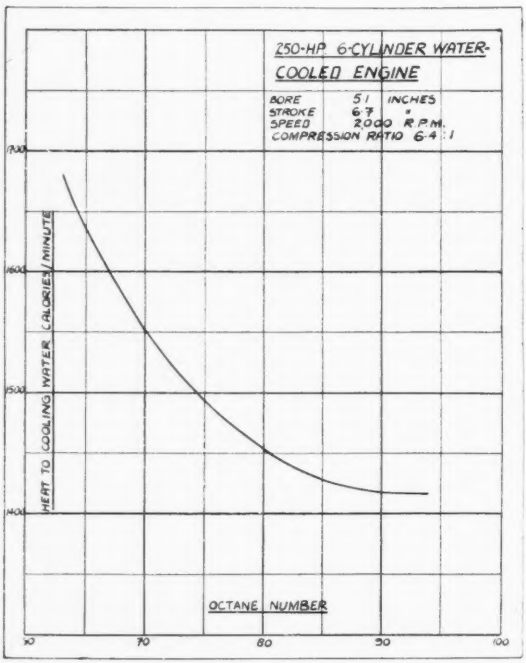


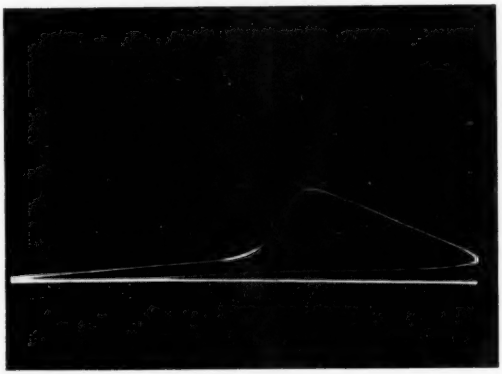
FIG. 9.

very complete investigation of the subject on these lines. His experiments were carried out on a six-cylinder water-cooled engine of 250 h.p. at 2,000 r.p.m. and having a compression ratio of 6.4 to 1. The method employed was to run the engine under constant conditions of throttle opening, mixture strength, ignition advance and speed, and to measure the variation in heat losses to the cooling water (in terms of calories/minute) when using various fuels of differing knock-ratings. An increase in heat to the cooling water of the order of 16 per cent. was recorded under conditions of detonation as compared with no detonation. The actual variations in heat loss and temperature measured on such a test are shown in Fig. 9. It was found important in these experiments to maintain the water inlet temperature constant owing to the fact that comparatively large variations in heat losses occurred with variations in inlet water temperature. For example, a rise in inlet water temperature of 28°C. accounted for a decrease in heat losses to the cooling water of 12½ per cent. on a given fuel.

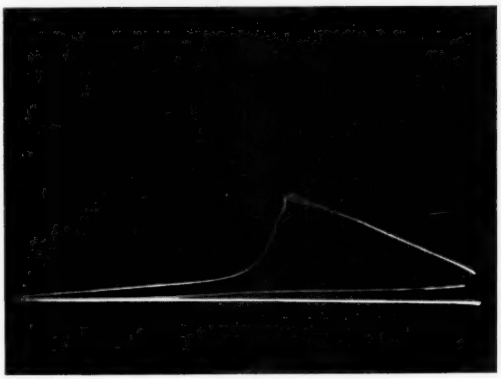
[11] Etude sur la Transmission de la Chaleur à l'Eau de Refroidissement dans un moteur d'aviation. Par M. Champsaur. Publications Scientifiques et Techniques du Ministère de l'Air, No. 17.

Similar experiments were described in a paper by Monsieur Dumanois[12] read before the World Petroleum Congress, 1933. The engine used was one of 250 h.p. running at 2,000 r.p.m. and having a compression ratio of 6.2 to 1. For the experiments the engine was operated at 1,600 r.p.m. and under these conditions the increase in heat to the cooling water amounted to 30 per cent. when running with detonation above that when running free from detonation.

Optical Indicator Diagrams.
C.F.R. Engine.



No detonation.



Slight detonation.

FIG. 10.

Thus it is clear that given sufficiently accurate means of measuring water flow and temperature, this method can be used for the detection of detonation in water-cooled engines. The need for this extreme accuracy somewhat detracts from the practical value of the test, however, and it is exemplified by the fact that both Champsaur and Dumanois found it necessary to use thermometers reading to 0.05°C., whilst in Champsaur's experiments the water outlet temperature varied only about 2°C. and covered the range from heavy to no detonation.

[12] Au Sujet des Méthodes de Détermination de la Détonation employée en France. Par M. P. Dumanois. Proc. World Petroleum Congress, London, 1933, Vol. II.

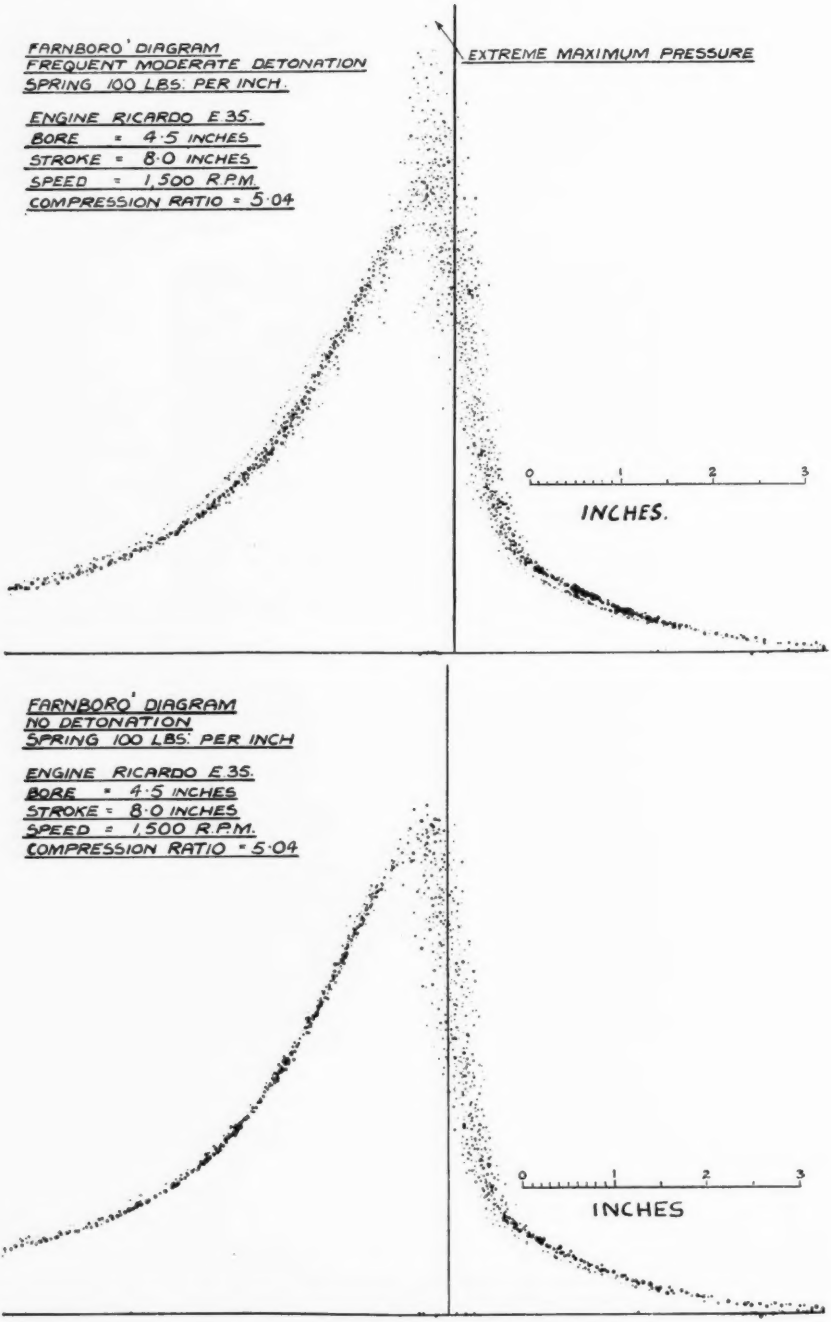

FARNBORO' DIAGRAM
FREQUENT MODERATE DETONATION
SPRING 100 LBS. PER INCH.
ENGINE RICARDO E 35.
BORE = 4·5 INCHES
STROKE = 8·0 INCHES
SPEED = 1,500 R.P.M.
COMPRESSION RATIO = 5·04
EXTREME MAXIMUM PRESSURE
0 1 2 3
INCHES.
FARNBORO' DIAGRAM
NO DETONATION
SPRING 100 LBS. PER INCH
ENGINE RICARDO E 35.
BORE = 4·5 INCHES
STROKE = 8·0 INCHES
SPEED = 1,500 R.P.M.
COMPRESSION RATIO = 5·04
0 1 2 3
INCHES

FIG. 11.

There are obvious difficulties in the way of employing exactly Champsaur's method for the detection of detonation on air-cooled engines. The direct measurement of the temperature of the cylinder heads of air-cooled engines for this purpose is, of course, quite common practice and makes use of the same phenomenon as Champsaur employed. Further reference is made to this later.

An explanation for the greater heat losses accompanying detonation introducing a theory that they are due to the increased turbulence occurring with detonation is dealt with in Appendix 7.

(*e*) *Measurement of Combustion Pressures*

The combustion process during detonation is typified by the uncontrolled combustion of some portion of the charge in the combustion chamber. Generally this type of combustion will produce higher pressures than the controlled burning associated with normal combustion, whilst the extent of these increased pressures will depend upon the proportion of the charge which detonates. Indicator diagrams taken under conditions of moderate and no detonation on the C.F.R. engine are reproduced in Fig. 10. These diagrams were taken with the Delft[13]

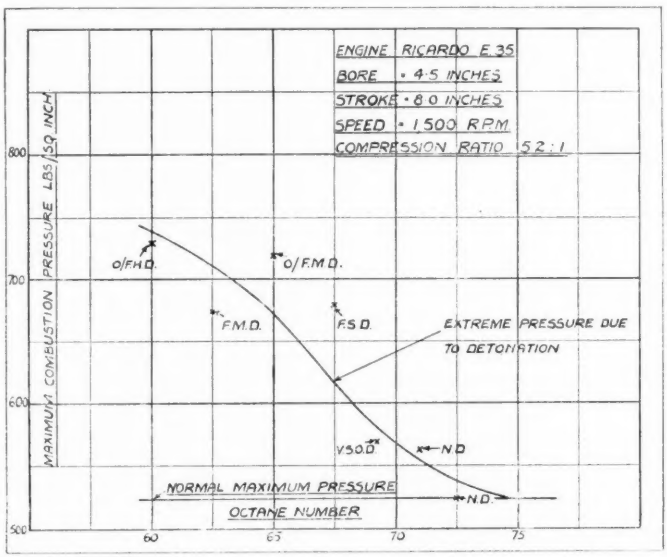


FIG. 12.

optical indicator which is able to record the pressures throughout a single cycle, a feat which the Farnborough instrument is incapable of achieving. Due to the irregularity of detonation, even when the engine is said to be running with continuous detonation, indicator diagrams taken with the Farnborough under such conditions merely show a wide scattering of the " spots " as shown in Fig. 11. Maximum combustion pressures can, however, be measured by the Farnborough instrument (or, more simply by the Farnborough maximum pressure indicator) and, since these may be taken as representing the amount of detonation occurring, they can be utilised for the purpose of determining the exact fuel requirements of an engine. For this purpose a series of fuels of different anti-knock values

[13] Ignition Quality of Fuels in Compression-Ignition Engines, by G. D. Boerlage and J. J. Broeze, " Engineering," 13th November, 4th and 18th December, 1931.

are needed, these to be both above and below what it is expected are the known requirements of the engine. The maximum combustion pressures on each fuel can then be measured, other conditions remaining constant, and the results plotted against the knock-rating of the fuel. The results of such a test on the E.35 engine are shown in Fig. 12. The point at which the lowest maximum pressures are first obtained is on the fuel of lowest knock-rating which will give freedom from detonation under the conditions of test.

It should be pointed out that these observations are contrary to those made by Dr. Mucklow in connection with his experiments on supercharged engines. Dr. Mucklow states in his report[14] that: —

> "There is no evidence that the occurrence of even heavy detonation gives rise to any general increase in maximum pressure."

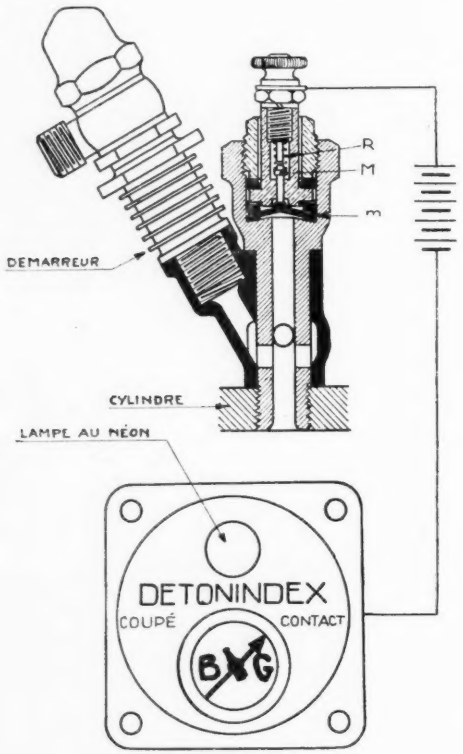


FIG. 13.

An increase in maximum pressure was recorded, however, when pre-ignition occurred.

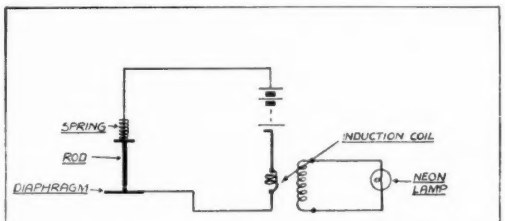
A point which should be mentioned here is the effect of the position of the indicator valve in the cylinder head and the type of indicator used. Obviously the largest variations in pressure should occur when the valve is in a position (usually remote from the sparking plugs) where the full effect of the detonation

[14] Experiments with a Supercharged Single-Cylinder Unit, by G. F. Mucklow, D.Sc. R. & M. 1460.

wave will be felt. Otherwise only comparatively small variations in maximum pressure may be recorded and some of the sensitivity of the method will be lost.

It is important also that a low inertia indicator is used for this purpose owing to the extremely short duration of the extreme maximum pressure period during detonation. Maximum pressure indicators such as the Okill are quite unsuitable. The indicator used by Dr. Mucklow consisted of a Bourdon gauge coupled to the combustion chamber by a non-return valve. This valve allowed the pressure in the connecting pipe gradually to build up until it reached a maximum which balanced the average maximum pressures in the cylinder. There appears to be no reason why this type of indicator should not give reliable results, providing the non-return valve used is not too heavy.

An instrument of the greatest promise for work of this nature is the indicator developed by Dr. Labarthe of the Faculté des Physiques et Chemiques of the Université de Paris. This indicator translates light reflections from a diaphragm in communication with the combustion chamber into a spot on a screen by means of a photo-electric cell and a cathode ray oscillograph. The natural frequency of the diaphragm can be made very high, and since there is virtually no inertia in the electrical circuits, extremely accurate diagrams are obtained from which the effects of detonation can be observed instantaneously. Further, the use of valve amplifiers between the photo-electric cell and the oscillograph enable magnification of any part of the diagram to be made at will.



THE 'ROD' IS HELD AGAINST THE 'DIAPHRAGM' UNDER NORMAL RUNNING CONDITIONS, BUT IS 'BOUNCED' AWAY FROM IT BY THE EXTREMELY RAPID DEFLECTION OF THE 'DIAPHRAGM' RESULTING FROM THE RAPID PRESSURE RISE DUE TO DETONATION.

SCHEMATIC ARRANGEMENT OF THE 'B.G. DETONINDEX'

FIG. 14.

(*f*) *Measurement of Rate of Pressure Rise*

The " Detonindex " is the invention of Monsieur Serruys and is designed to indicate the occurrence of excessive rates of pressure rise which are associated with detonation (see Fig. 10). The essential part of the apparatus (Fig. 13) is a very rigid diaphragm " m," with a natural frequency of 25,000 cycles/second which is exposed to the explosion pressure in the cylinder head and therefore deflects with rises in pressure in the head.

A small rod " M " is held against the diaphragm by a spring " R " so designed that for the relatively slow pressure rise which occurs in normal running, the rod is kept in contact with the diaphragm throughout the whole cycle, whereas the extremely rapid pressure rise which occurs under detonating conditions serves to " bounce " the pin away from the diaphragm.

The rod and diaphragm are connected in series with a battery and the primary of an induction coil; a neon lamp is connected across the secondary, as shown in Fig. 14. When the primary circuit is broken by the rod being

" bounced " away from the diaphragm owing to detonation, there is a momentary rise in potential across the secondary, which lights the neon lamp.

The diaphragm holder is designed to be fitted in the starter plug hole and incorporates a connection for gas or compressed air starting. The normal aircraft battery can be used to operate the apparatus and the neon lamp can be mounted on the dashboard of an aircraft so that it can be used to detect detonation whilst actually in flight.

There may be some objection to this type of indicator for engines not fitted with gas or air starters on the grounds that they necessitate the head being drilled.

(*g*) *Measurement of Cylinder Head Temperature*

The direct measurement of cylinder head temperatures of air-cooled engines can be a most satisfactory method of detecting detonation. The apparatus required is simple and reliable and can be made part of normal aircraft equipment, as indeed is standard practice in practically all American machines to-day. Thermo-couples of either the " rivet " or " sparking plug washer " type are obtainable from instrument makers specialising in this equipment. The rivet type plug is usually considered to be more satisfactory for the reason that it gives better thermal contact and may be put in whatever position in the head which may be found to give the widest temperature variations.

On aircraft installations it is usual only to fit one cylinder of each engine with a thermo-couple—the cylinder selected being that known by experiment to be the hottest running. In multi-engined machines (or for the temperature measurement of a number of cylinders) a suitable change-over switch may be employed to avoid duplication of the milli-voltmeter, although even this is considered unnecessary on some installations on which one particular engine is known to run hotter than the others, as, for example, the centre engine of a triple-engined machine. With the growing tendency to use cylinder head thermometers for engine control, however, it is desirable for each engine to be equipped.

The use of the cylinder head pyrometer has the added advantage that it may also be used by the pilot for mixture strength adjustment and for the control of climbing conditions to avoid overheating. In fact, " flying on the cylinder head pyrometer " is becoming common practice on those machines with the necessary equipment and has much to recommend it. Engine manufacturers should now be in a position to state what are normal and maximum permissible temperatures for various conditions of flight.

Little direct evidence of the sensitivity of the cylinder head pyrometer as a detector of detonation is available. Cases have been known where detonation has caused piston trouble in spite of the fact that manufacturers' figures for cruising and climbing conditions were not exceeded, but this might be considered to be more a question of giving too generous temperature limits rather than one of unreliability of the method. Nevertheless, it is clear that with the quite considerable heat capacity of the cylinder head of a large engine a certain time lag must occur between the occurrence of the conditions causing rise of temperature in the combustion chamber and the recording of them by the cylinder head thermometer. The sensitivity of the apparatus will obviously depend upon the distance of the thermo-couple from the combustion chamber walls—the best position for the couple being actually within the combustion chamber. Experiments have been conducted on the E.35 engine, using the temperature plug which projects 30 mm. into the combustion chamber to compare its sensitivity with the normal sparking plug washer thermo-couple. For these experiments two types of cylinder head temperature plug were employed, the first being of the type just referred to projecting 30 mm. into the combustion chamber and fitted with a chromel-alumel couple; the second plug was of slightly modified design and projected 10 mm. into the combustion chamber and was fitted with

an iron constantan couple. The sparking plug washer thermo-couple was a standard fitting as supplied for use on American aero engines.

The change of temperature conditions was effected by suddenly altering the mixture strength by varying the gross consumption from 17 to 25 pints per hour. This was effected in about half a second by turning the needle valve of the variable jet of the carburettor. The results obtained are shown in Fig. 15. Admittedly, the sensitivity of the plug washer thermo-couple in a water-cooled engine is poor and a better comparison would have been obtained on an air-cooled unit. Unfortunately facilities for this were not available.

In any case, for engine development work it is desirable to make special investigations with each type of cylinder to ascertain the best position " on " and " in " the cylinder head for the maximum sensitivity to be obtained.

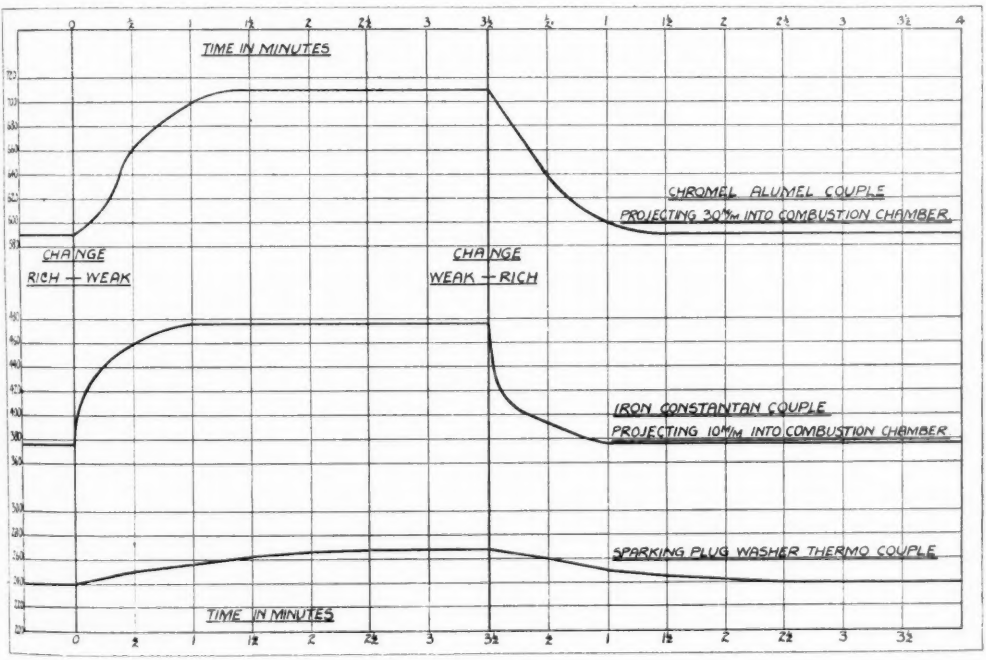


FIG. 15.

(*h*) *C.F.R. (Aviation Gasoline Detonation Sub-Committee) Method*

[15]The work of this committee is now directed towards finding whether or not the knock-ratings of fuels as given by the C.F.R. motor method[16] correlated with the behaviour of widely diverse types of fuel when run in a full-scale engine. The method of assessing the quality of fuels on the full-scale tests by taking into consideration head and cylinder base temperatures, power output and specific fuel consumption is of the greatest interest. A mixture control run is made on each test fuel and reference fuel with the throttle locked at a point just giving

[15] See Reference No. 8.

[16] The C.F.R. motor method was adopted temporarily by the C.F.R. Committee for determination of the knock-rating of aviation gasolines pending the completion of the present series of tests (*vide* page 883).

satisfactory performance for the fuels compared. A typical set of results is shown in Fig. 16. From these the performance of the test fuel is judged in relation to the reference fuel used. The committee have actually accumulated sufficient data to enable them to estimate the difference in knock-ratings of fuels so tested in terms of octane numbers. In the results reproduced in Fig. 16 it will be seen that of the two test fuels of 80 and $83\frac{1}{2}$ (C.F.R. motor method) octane

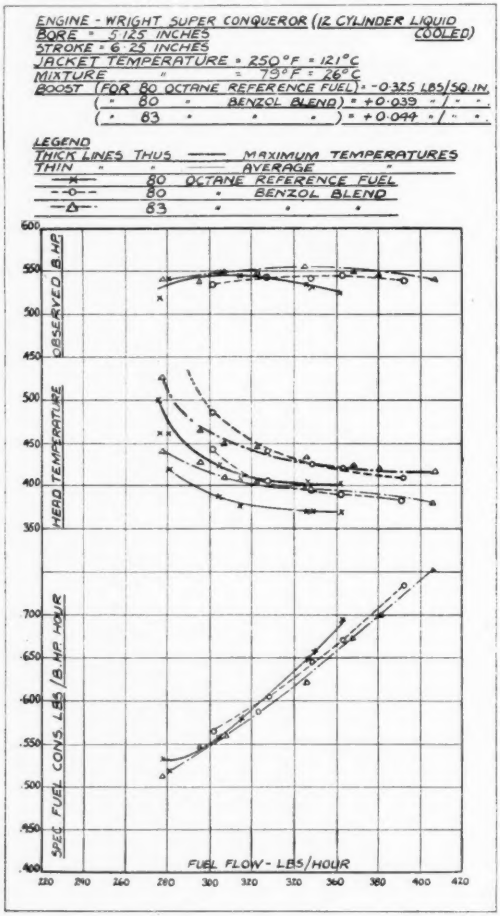

ENGINE - WRIGHT SUPER CONQUEROR (12 CYLINDER LIQUID COOLED)
BORE = 5·125 INCHES
STROKE = 6·25 INCHES
JACKET TEMPERATURE = 250°F = 121°C
MIXTURE " = 75°F = 26°C
BOOST (FOR 80 OCTANE REFERENCE FUEL) = -0·325 LBS/SQ IN.
(" 80 " BENZOL BLEND) = +0·039 " / " "
(" 83 " " ") = +0·044 " / " "
LEGEND
THICK LINES THUS —— MAXIMUM TEMPERATURES
THIN " " —— AVERAGE "
—x— 80 OCTANE REFERENCE FUEL
--o-- 80 " BENZOL BLEND
—Δ— 83 " " "
OBSERVED B.HP
HEAD TEMPERATURE
SPEC FUEL CONS. LBS/B.HP HOUR
FUEL FLOW - LBS/HOUR

FIG. 16.

number consisting of benzol blends, the former was markedly inferior to the 80 octane reference fuel. The committee analysing the results estimate the effective knock-rating of the $83\frac{1}{2}$ octane number benzol blend to be $3\frac{1}{2}$ octane numbers lower than the value given to it by the C.F.R. motor method.

In order to obtain quantitative measurement for the evaluation of fuels a method suggested by Mr. A. L. Beall, of the Wright Aeronautical Corporation, is of interest and details of this are given in Appendix No. 6.

The results so far obtained are said to indicate that for straight run fuels comparatively good correlation was obtained with the C.F.R. motor method ratings, but for benzol blends the rating given by the C.F.R. was high. Some discrepancies have also been observed with cracked fuels, and it appears from the results so far published that any changes in the laboratory method of fuel testing should not be in the direction of decreasing the severity of the present C.F.R. motor method.

(*i*) *Measurement of Exhaust Gas Temperature*

With the complete upset of the combustion process under detonating conditions, introducing, as already shown, variations in pressure and temperature, it appeared logical that this should reflect in some variation in the exhaust gas temperature. Taking into consideration the increased heat losses and maximum combustion pressures occurring with detonation it was expected that under those conditions the exhaust gas temperature would be reduced. Preliminary experi-

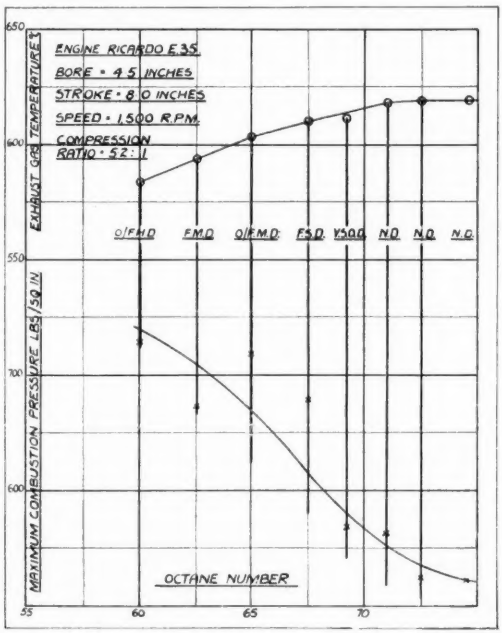


FIG. 17.

ments carried out on the E.35 engine showed this to be the case. The tests were made with the engine conditions maintained constant, but using a range of fuels of different anti-knock value. The results of these tests are given in Fig. 17, which also gives the maximum combustion pressures recorded under similar conditions and previously shown in Fig. 12. The point of greatest interest in these results was that at the point at which detonation was completely suppressed, the exhaust gas temperature reached a maximum, and any further increase in the anti-knock value of the fuel failed to produce any variation in the exhaust gas temperature. No attempt was made to measure actual exhaust gas temperatures as may be judged from the comparatively low figures recorded, but since only relative figures are required, the " mean " results obtained were deemed

satisfactory. All that is needed is for the thermo-couple to be situated near enough to the exhaust port to ensure a reasonable degree of sensitivity to the variations of the gas temperature. The thermo-couple used on the E.35 was similar to that developed for cylinder head temperature measurements and referred to below. The exhaust gas thermo-couple was located in the outlet pipe 14.7 cm. equi-distant from the centres of the two exhaust valves.

For the purpose of checking up the conclusions drawn from the exhaust gas temperature tests, experiments were made with cylinder head temperature plugs. The first of these was made to fit flush with the wall of the combustion chamber, but this was found to give poor sensitivity and repeatability. Another plug projecting into the combustion chamber 30 mm. was then tried and gave very satisfactory results. The design of the plug is shown in Fig. 18. Contrary to expectations this plug did not give rise to pre-ignition, nor indeed, did it appear to encourage detonation appreciably, doubtless on account of the comparatively low output of the engine on which the plug was used.

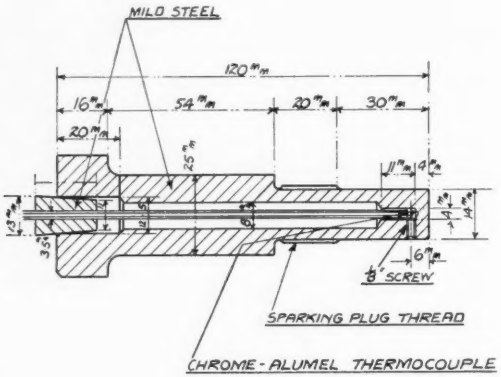


FIG. 18.

B.P.M. thermo-couple for E.35 engine.

The results of the experiments on which cylinder head and exhaust gas temperatures were simultaneously recorded are given in Fig. 19. It is interesting to observe that at the complete elimination of detonation (by improving the fuel quality) both exhaust gas temperature and cylinder temperature curves become asymptotic. This was considered a satisfactory check on the exhaust gas temperature measurement as a means of indicating detonation.

It is suggested that the method may be used on any engine which is coupled to a brake by running a series of tests on fuels of different anti-knock value. The fuels selected should be both below and above the knock-rating of the fuel normally specified for the particular engine, the range being about six octane numbers below and six above. Owing to the sensitivity of exhaust gas temperature to variables such as mixture strength and ignition timing, it is imperative that these be kept constant throughout the series of tests. For this reason it is very necessary that the same type of fuel be used and this can best be achieved by using ethyl fluid for the purpose of giving the range of knock-ratings required. Thus, supposing an engine normally requiring 77 octane fuel is to be tested, a basic fuel of about 71 octane number would be needed. The requisite quantities of tetra-ethyl lead to be added to give a range of fuels from 71 to 83 octane number in steps of about three octane numbers, can then be ascertained from a lead curve for that particular fuel as determined by a knock-testing engine. Each fuel will then be run long enough in the engine on test to obtain a steady

exhaust gas temperature reading and the results plotted, using octane number as abscissæ and exhaust temperature as ordinates. The first point on the resultant curve at which maximum exhaust gas temperature is recorded is at the minimum octane number at which detonation is absent.

This method of testing for detonation has the advantage of simplicity and flexibility, and although the number of engines in which it has been applied are limited up to the present time the results obtained show that the method gives reliable indication of detonation. It will be seen from Fig. 17 that the sensitivity of the exhaust gas temperature method is appreciably greater than the aural method on the E.35 engine, with the additional advantage that the personal element introduced when judging detonation by sound is eliminated. This is of special interest in view of the high degree of skill acquired by the engine operators in detecting detonation on the E.35 and of the fact that the detonation sounds are well marked and easy to hear in comparison with those from air-cooled aircraft engines from which there is generally a great deal of extraneous mechanical noise.

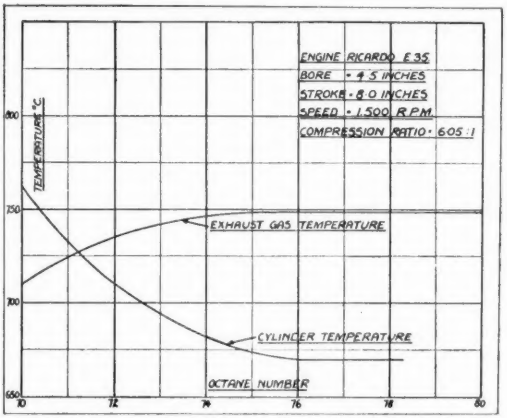


FIG. 19.

Care is needed in the use of exhaust gas thermometers on account of their sensitivity of external conditions. For example, with the thermo-couple as installed on the E.35, it was found a change of draught in the engine-room had an appreciable effect on the temperatures recorded. Doubtless this difficulty can be overcome by suitable design and installation of the thermo-couple. For the type of experiments described it was not thought necessary to do this as only relative results were required and, with reasonable care and control, satisfactory and repeatable results were obtained with the apparatus used.

Temperature Measurement Experiments

A certain amount of experimental work has been carried out on the E.35 engine, using the cylinder head and exhaust gas pyrometers referred to in the previous section of the paper. Primarily the effects of mixture strength and fuel anti-knock characteristics were examined, the following notes being a general discussion of the results obtained.

(*a*) *Effect of Mixture Strength*

The effect of varying the mixture strength on exhaust gas and cylinder head temperatures at full and 70 per cent. load is shown in Fig. 20. As would be

expected the maximum temperatures occur at near to the theoretically correct mixture strength for complete combustion as determined by exhaust gas analysis. The sensitivity of the method is apparent, the full load temperature range from 8 per cent. weak to correct mixture strength being 40°C. Moreover, the time lag between changing the mixture strength and indication on the milli-voltmeter is so small that adjustment of the mixture strength can be carried out extremely rapidly with the aid of either the exhaust gas or cylinder head pyrometer.

An interesting check on the E.35 temperature tests is obtained by comparison of the results with those obtained by Professor Gibson[17] on an air-cooled single-cylinder engine. In these experiments exhaust valve temperatures were measured at the centre of the exhaust valve head by means of a thermo-couple inserted through the hollow stem. Fig. 21[18] shows the variations in temperatures of exhaust valve and cylinder head at different mixture strengths and speeds. Here again, maximum temperatures are recorded at nearly the theoretically correct mixture strength. If anything, the exhaust valve temperature reaches a maxi-

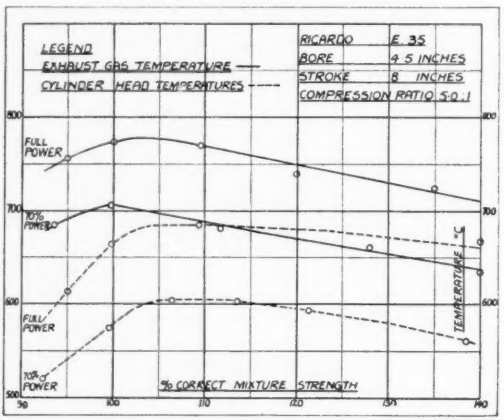


FIG. 20.

mum with a mixture slightly weaker than correct, the tendency being for the maximum to occur under increasingly weak mixture strengths as the speed of rotation is raised.

The experiments of Evans and Watts[19] have also shown that the gas temperature at 80 degrees after top dead centre increases to a maximum at approximately " correct " mixture strength which, again, is in line with the E.35 exhaust gas temperature measurements.

Taking into consideration the fact that maximum power mixture strength on full-scale multi-cylinder engines is from 15 to 20 per cent. rich, it is easy to see that higher general cylinder temperatures must be expected when the mixture strength is weakened, at any rate, on those cylinders which, on account of inequalities in distribution, are receiving rich mixtures. The reason is not so evident, however, for the exhaust valve burning which sometimes takes place under cruising conditions when it is known that the engines in question will stand prolonged full throttle running on full power mixture strength without signs of exhaust valve burning developing. Reference to Fig. 20 shows that even the

[17] Exhaust Valve and Cylinder Head Temperatures in High-Speed Petrol Engines, by Prof. A. H. Gibson, D.Sc., and H. Wright Baker, M.Sc. Proc. Inst. Mech. Engs.

[18] Reproduced by permission of the Institution of Mechanical Engineers.

[19] A Contribution to the Study of Flame Temperatures in a Petrol Engine, by B. Lloyd Evans and S. S. Watts, " Engineering," 11th January, 1935.

maximum temperatures recorded at 70 per cent. load (approximating cruising conditions) are lower than those at full throttle and 15 per cent. rich. It can only be suggested that the nature of the exhaust gases, *i.e.*, whether reducing, " neutral " or oxidising is the controlling factor as far as the exhaust valve is

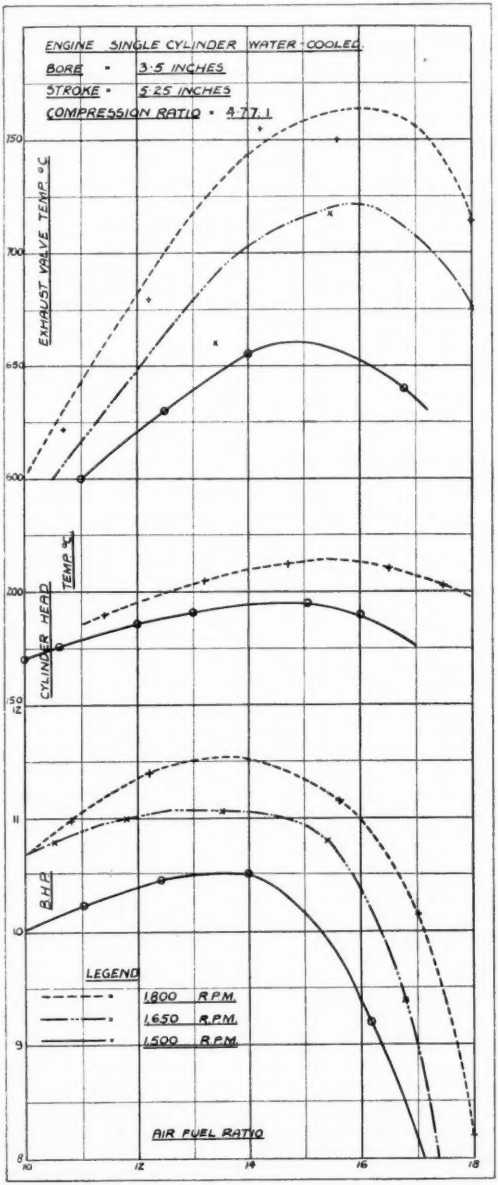


FIG 21.

concerned. On the other hand, it appears unlikely that a multi-cylinder engine would run steadily on any mixture from the carburettor much weaker than " correct " and therefore the exhaust flame with the greatest tendency to an oxidising condition would only be " neutral." Inequalities in distribution will, of course, account for some cylinders receiving a mixture considerably weaker than " correct," and the exhaust valves of those would certainly be subjected to an oxidising flame. Careful analysis of the exhaust gases from individual cylin-

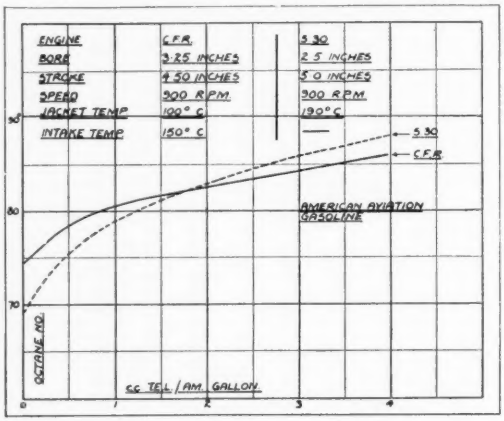


FIG. 22.

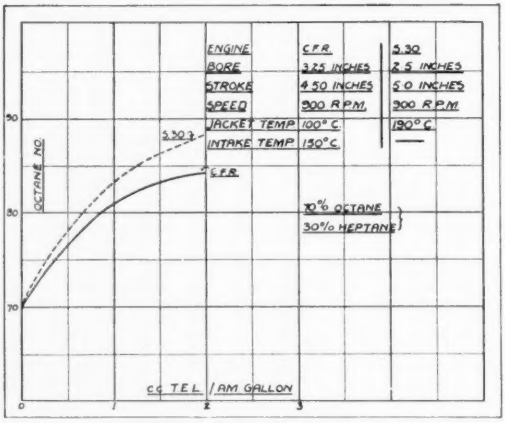


FIG. 23.

ders can elucidate this point, but great difficulties would be experienced in obtaining representative gas samples which would have to be taken close to the exhaust valve.

One other factor to be remembered in connection with weak mixture running is that any increased tendency to detonation may be still further aggravated by the combustion of the lubricating oil passing into the combustion chamber.[20]

[20] Detonation and Lubricating Oil, by R. O. King, M.A.Sc., and H. Moss, D.Sc. R. & M. 1318 and 1362.

With rich mixtures a smaller quantity of the oil will be burnt and will therefore have less effect in inducing detonation than at the weaker mixtures of greater oxidising character.

(*b*) *Effect of Fuel Anti-Knock Characteristics*

So far, the effect of varying the anti-knock value of a given type of fuel has been considered. The fact is disquieting, nevertheless, that fuels of the same anti-knock value as determined by the standard test method may vary considerably when tested by other methods.[21] This is one of the major difficulties encountered in the development of fuel testing engine methods to give correlation with full-scale engines. The following table shows the range of results which may be obtained from four fuels of similar anti-knock value under one set of engine test conditions:—

		Octane No.			
Engine.	Test Conditions.	Straight Aviation. Gasoline	Straight Aviation Gasoline.	75 % Aviation Gasoline 25% Benzol.	Aviation Gasoline + 2·6ccs. T.E.L./ Imp. Gall.
C.F.R.	Motor method* ...	72	72	81	81
	Aviation method† ...	73	73½	83	82
S.30	900 r.p.m., 190°C. jacket	63	70½	71	80
	600 ,, 150°C. ,,	72	74	86½	87

* Intake temperature 300°F.
† ,, ,, 260°F.

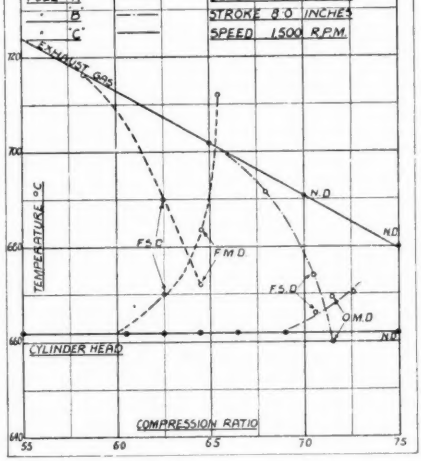


FIG. 24.

Even more perplexing is the effect of the different test methods on the shape of the lead response curve, as illustrated in Figs. 22 and 23. Admittedly the tests made by the Institution of Petroleum Technologists have shown that good correlation can be obtained between full-sized single-cylinder aircraft engines and the C.F.R. engine, but it may be questioned as to whether the tests were carried out under truly representative conditions. In particular the method of

[21] The Effect of Temperature on Knock-Rating, by L. A. Peletier. Proc. World Petroleum Congress, London, 1933

judging detonation by aural means may be criticised since it has already been shown that quite an appreciable degree of detonation may be present before it becomes audible. Now in Fig. 24 the results of temperature tests are illustrated on two fuels of similar C.F.R. (motor method) octane number but different chemical characteristics. In these experiments the combustion chamber and exhaust gas temperatures were first measured at a compression ratio at which it was assured that no detonation was present. The compression ratio was then raised and the steady temperature recorded after each increment in compression ratio. For the purpose of comparison the temperatures are given which were obtained on a fuel with which detonation was entirely absent over the range of compression ratios embraced. It is clear from the results, that as conditions for detonation become increasingly severe, the rate of increase of detonation is greater with one fuel than with the other, the more satisfactory one being that having its temperature curves lying nearer to the no-detonation curve. These results show that for equal intensity of knock judged aurally the compression ratios on the two fuels and the temperatures recorded in relation to the non-detonating fuel were as follows:—

Fuel.	Compression Ratio.	Exhaust Gas Temperature.	Combustion Chamber Temperature.	Detonation Sound.
A	6.25	−17.0°C.	+8.0°C.	Frequent slight.
B	6.25	0°C.	+ 0°C.	None.
A	7.05	—	—	Too heavy to run.
B	7.05	−15.0°C.	+5.0°C.	Frequent slight.

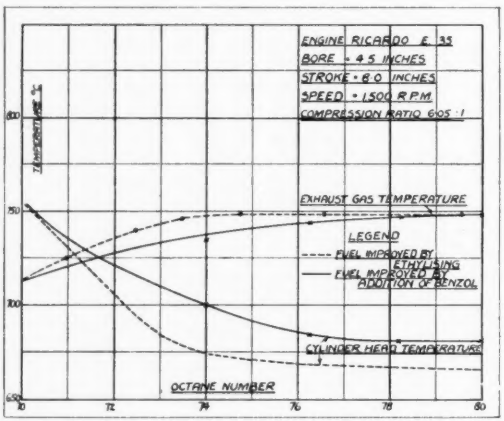


FIG. 25.

It is obvious that if a degree of detonation of the order of " Frequent slight " is considered as the maximum safe limit for an aircraft engine, the effective knock-ratings of the two fuels would be quite different.

Wide variations of the same order occur when comparisons are drawn between leaded fuels and benzol mixtures.[23] The temperatures recorded with the engine running under constant conditions but with fuels of different anti-knock

Highest Useful Compression Ratio = Compression ratio at which maximum power is recorded. The audible degree of detonation occurring at the H.U.C.R. is known as " Frequent Moderate."

[23] See also Figs. 5 and 6, " Ethyl," by F. R. Banks. Proc. Royal Aeronautical Society, 1934.

value are given in Fig. 25. In one case the anti-knock value of the basic gasoline was raised by the addition of tetra-ethyl lead whilst in the other benzol was used. These results show the leaded fuel to considerable advantage since the exhaust gas and combustion chamber measurements indicate the complete suppression of detonation at an anti-knock value of 75 octane number on the leaded fuel and 79 on the benzol mixture.

The correct interpretation of the various experiments described needs some care in view of the fact that they have been carried out on the E.35 engine which may not be regarded as capable of giving results directly comparable to those of an aircraft engine—particularly one of high output and air-cooled. However, in so far as the relative effects of the various fuels tested are concerned, it is safe to say that the hotter cylinders of aircraft engines are more likely to accentuate the differences observed than otherwise. The problem also leads to the much deeper one of what degree of detonation should be permitted on aircraft engines to enable a reasonable degree of safety to be maintained and at the same time the maximum benefit taken of the fuel available. Also, the question arises as to whether it is desirable to persist in measuring detonation at heavy knock in fuel-testing engines when it is clear that no such degree of detonation could be tolerated in an aircraft engine. From the somewhat limited experiments described above, it seems that further correlation tests embracing the tests made under incipient or early knock conditions are necessary. Similarly, the relative merits of knock determinations at maximum knock mixture strength and maximum power or maximum temperature mixture strength need investigation.

(*c*) *Effect of Intake Mixture Temperature*

The effect of varying intake mixture temperatures on the anti-knock values of fuels has already been touched upon and is clearly illustrated by the curves given in Appendix No. 3. This effect appeared most likely to be important in supercharged engines in which the mixture becomes pre-heated according to the amount of boost and the efficiency of the blower. The evidence available appears to be conflicting, however, the experiments of Ricardo[24] on a sleeve valve engine showing that an intake mixture temperature range of from 25°C./30°C. to 75°C./80°C. had no appreciable effect on the tendency to detonation up to boost pressures of 3.5 atm. (absolute). On the other hand, results from poppet valve engines indicate that pre-heating the mixture does have some effect in the direction of promoting detonation.

In either case the problem is closely related to that of the influence of the residual products of combustion in suppressing detonation and it would be useless to attempt to enlarge on the comprehensive information on this subject already available in the reference given below.[24]

One further word might be added, however, in connection with the rating of fuels for supercharged engines. On normally aspirated engines the tendency to detonation diminishes rapidly as the throttle is closed, so that even if a certain amount of detonation is permitted under full throttle (take-off) conditions, it is unlikely that any detonation will occur when the engine is running throttled at 60 to 70 per cent. load when cruising. With the supercharged engine the closing of the throttle will result in reduced fuel flow to the supercharger (particularly with " economiser system " carburettors) with subsequent diminution in cooling effect. The reduction in temperature in the supercharger due to the smaller mass of mixture to be compressed may not compensate for this loss of cooling effect of the fuel, depending upon the mechanical and volumetric characteristics of the supercharger.

It can be expected, therefore, that even under the most favourable conditions the tendency to detonation will diminish less under throttled conditions with the

[24] The Internal-Combustion Engine, Vol. II, by D. R. Pye.

supercharged than with the normally aspirated engine. The increasing use of supercharged engines in civil and military aviation requires further investigation on this problem and also lends support to the suggestion that no engine should be rated on a fuel in which any degree of detonation is present as may be determined by exhaust gas temperature tests.

(*d*) *Effect of Ignition Timing*

Fig. 26 shows the influence of ignition timing on B.M.E.P. and cylinder and exhaust gas temperatures on the E.35 engine when running at full power mixture strength. The large effect which the ignition timing has on the temperatures measured, clearly indicates the necessity for maintaining the timing constant when the effect of other variables is being investigated.

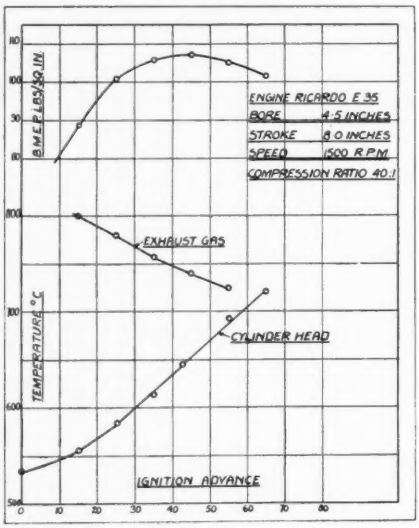


FIG. 26.

Boiling Range

Petroleum spirits boil over a range of temperatures as opposed to the definite boiling point of chemically pure liquids. The conventional way of showing the boiling range of gasolines is by distillation curves (Fig. 27) from which the percentage of fuel distilled off at any given temperature can be determined. The apparatus and method most commonly used is that specified by the American Society for Testing Materials (A.S.T.M.) and the Institute of Petroleum Technologists.

The boiling range is of considerable importance, since it controls, *inter alia*, the following important characteristics:—

Startability.
Distribution.
Lubricating oil dilution.
Tendency to form ice in the carburettor.

In addition, it bears some relation to the vapour pressure of the fuel, the practical importance of which is considered under a separate heading.

(*a*) *Startability*

Experimental evidence has shown that until very low temperatures are reached the startability of a gasoline is roughly dependent upon the percentage distilling to 100°C. All aviation gasolines have at least 50 per cent. recovery to 100°C. against 30 to 40 per cent. for motor gasolines, from which it is obvious that the aviation gasoline will give better starting. On the other hand, the difficulties of rotating an aircraft engine from cold at a sufficiently high velocity to ensure the minimum of cooling, and therefore of condensation of the fuel through the long induction pipes necessary with a larger engine, considerably increase starting problems from the mechanical point of view. For this reason auxiliary priming devices are usually fitted to aircraft engines, but unless these are properly used they can lead to other starting difficulties through the mixture becoming too rich. It is quite possible that starting could be appreciably improved by using very special qualities of gasoline for the purpose, but for other reasons such fuels would be quite unsuitable for normal use.

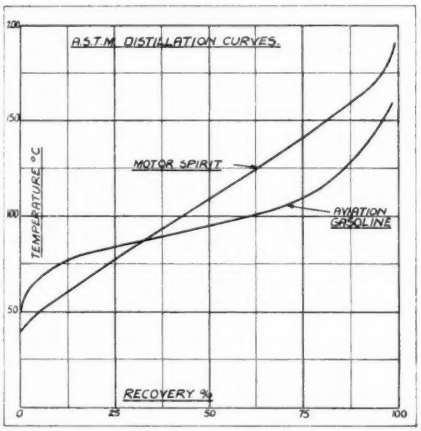


FIG. 27.

(*b*) *Distribution*

To obtain perfect distribution, *i.e.*, the supply of a perfectly homogeneous mixture of fuel and air in the same proportion to all cylinders, it is desirable for the fuel to be completely vaporised as soon as it issues from the carburettor jets. The presence of liquid fuel " blobs " of any appreciable size or quantity in the induction system almost certainly leads to unequal distribution. The readiness of any liquid to evaporate is determined by its dew point which is, of course, dependent upon the pressure of the surrounding atmosphere and to a small extent upon the ratio of fuel to air present. The dew point of normal gasolines (at atmospheric pressure) is approximately the same as that at which 65 per cent. is distilled off in the A.S.T.M. distillation apparatus. From the curve given in Fig. 27 it will be seen that for the aviation gasoline this temperature is 101°C. To pre-heat the ingoing charge to such a temperature would result in considerable loss in power in addition to increasing temperatures all round and also the tendency to detonation. This would appear to be sufficient argument for the use of fuels of much lower dew point, and although they can be manufactured they are quite unsuitable on account of their high vapour pressure[25] and tendency

[25] Vapour pressure is approximately inversely proportional to the temperature at which 10 per cent. is distilled.

to form ice in the induction pipe. For the moment, it is considered that modern fuels offer the best compromise available.

The problem of obtaining satisfactory distribution is ever before engine and carburettor manufacturers. Recent improvements in carburettors no less than the almost universal use of mechanical mixing fans and superchargers has enabled many improvements in distribution efficiency to be obtained. Nevertheless, experiments show that full-scale multi-cylinder engines need to run 15 to 20 per cent. richer than the equivalent single-cylinder engine to obtain the same relative B.M.E.P. This difference can usually be attributed to inequalities in distribution for the reason that it is possible to run over-rich in some cylinders without losing power which enables the mixture to those cylinders receiving the weakest mixture to be richened up to something approaching their maximum power mixture strength. This is possible because the loss in power accompanying the use of mixtures richer than maximum power mixture strength is less than that when the mixture is weakened, as illustrated in Fig. 28.

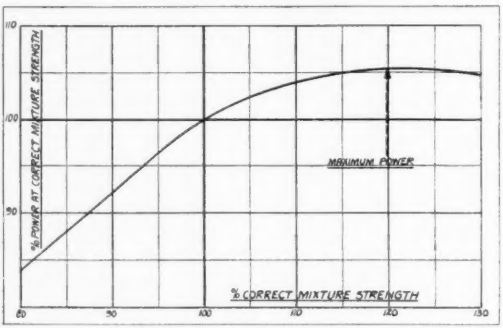


FIG. 28.

Some interesting experiments[26] have been carried out at the R.A.E. using butane (boiling point 1°C.) and aviation gasoline to ascertain whether improved distribution would be obtained with the gaseous fuel to account for the observed discrepancies between complete engine and single-cylinder mixture strengths at full power.

The general conclusions drawn were that in the engines tested (Jupiter VIII and Kestrel II S.) the distribution of liquid fuel was better than anticipated, but a small gain in performance of the order of 3 per cent. might be obtained by improvements of the carburation or induction systems. Nevertheless, it seems doubtful whether these deductions are sufficiently conclusive for application to all types of engines, particularly when running with very weak mixture strengths when distribution and fuel supply and homogeneity in successive cycles becomes of increasing importance.

Dependent also upon the dew point of the fuel is the tendency for the lubricating oil to be diluted. In actual fact this trouble is seldom experienced in aircraft engines when aviation gasolines are used. Diluent contents of the oil exceeding 1 per cent. are rare, and these are insufficient to cause any appreciable change in the viscosity of the oil.

Warming up periods and acceleration are also related to fuel volatility, although here again the variations met in aviation gasolines are insufficient to have any effect.

[26] Comparative Tests with Petrol and Butane, by P. H. Stokes and F. G. Code Holland. R. & M. 1570.

(*c*) *Tendency to Form Ice*

In an engine using a carburettor, the latent heat required to convert the liquid fuel into vapour is provided:—

1. By the intake air—which is usually pre-heated before entering the carburettor.
2. By contact with some heated surfaces (hot spots) in the induction system.
3. By contact with the hot surfaces of the cylinder head, piston, etc., during the suction and compression strokes.

The proportions of the total heat required which will be supplied from each of these sources will depend upon the volatility of the fuel, other conditions remaining the same.

The more volatile the fuel the greater will be the amount of evaporation taking place near the carburettor, thus abstracting more heat from the ingoing air and hot spot than would a less volatile fuel. The amount of heat required will, of course, depend upon the quantity and latent heat of evaporation of the fuel, and for ordinary petroleum spirits the latter varies but little from the average figure of 140 B.Th.U.'s/lb., whilst the quantity of fuel present is a function of the mixture strength.

If the temperature drop accompanying evaporation is sufficient to cool the air below its dew point the moisture in it will deposit and if temperature conditions are favourable this will turn to ice. A dangerous condition may arise if the ice formed accumulates on the throttle valve or venturi which will cause not only loss in power due to the throttling effect, but may result in the throttle becoming jammed in one position.

As the volatility of the fuel is increased and the amount of heat for evaporation taken from the intake air becomes greater, the tendency to form ice is also increased. The apparent anomaly is therefore explained that fuel of greater volatility may require more heating of the air intake, although it may be compensated for by reduced heat to the hot spot. Work carried out by the R.A.E.[27] showed that the ice-forming tendency of a fuel was related to the temperature at which 25 per cent. is distilled, but more recent experiments in America have produced a modified conclusion to this. A very complete investigation of the whole subject of ice formation in carburettors has been carried out by members of the National Bureau of Standards.[28] In the experiments conducted, the effect of all the variables introduced has been examined on a laboratory set up and the results obtained checked on a full-scale engine (Curtis D.12) working in an altitude chamber. The main conclusions drawn were:—

1. It can be predicted with reasonable certainty that ice will have formed in the induction system in sufficient amounts to effect an appreciable loss in engine power, or that this condition will be impending, at a temperature of the carburettor venturis about 5 Centigrade degrees below the dew point of the atmosphere, within the range of humidities likely to be encountered in flight, when the venturi temperature is at or below the freezing point.

The findings with the simulated carburettor set up—small-scale tests—approximate those with the engine, the difference being that the mean line of ice formation appears to be at least 1 Centigrade degree higher in the former case than in the latter, for reasons indicated in the text. Ice disappeared from the carburettor venturi in the small-scale tests at temperatures quite close to the dew point. The temperature at which ice disappeared could not be ascertained definitely in the engine tests.

2. The small-scale experiments have shown that the venturi temperature in

[27] Fuel Volatility and Carburettor Freezing, by W. C. Clothier, M.Sc., Wh.Sc. R. & M. No. 1549.

[28] Ice Formation in Aircraft Engine Carburettors, by H. H. Allen, G. C. Rogers and D. C. Brookes. S.A.E. Journal, November, 1934.

an unheated carburettor can be predicted with considerable accuracy in the service range when the mixture ratio supplied and the distillation characteristics of the fuel are known. To make similar predictions for the carburettor on an aircraft engine, the heat input to the carburettor must also be known or estimated.

3. For any particular engine operating under specified atmospheric conditions, the danger of ice formation tends to increase both with increasing richness of the mixture supplied by the carburettor and with increasing volatility of the fuel. As noted in Conclusion 1, venturi temperature and air humidity appear to define the danger zone.

4. The direct application of heat to control venturi temperature is a much more effective means of preventing ice formation than intake air heating and requires only a fraction of the energy input. Moreover, direct application of heat appears to have practically no adverse effect on engine power.

5. The A.S.T.M. corrected 50 per cent. temperature is shown to be a much more suitable index than the sum of the 10, 50 and 90 per cent. temperatures.

The last of these is interesting, in view of the requirement laid down in the U.S. Army specification for aviation gasoline (fighting grade) that the sum of the 10, 50 and 90 per cent. temperatures shall not be less than 260°C. So far as is known, this is the only specification in which provision has been made for the control of the ice forming characteristics of aviation gasoline.

The authors of the paper in question do not appear to have attempted to correlate their results with the dew point of the fuels used which, it is to be expected, is most likely to be a function of the ice-forming characteristic of the fuel.

For the purpose of practical comparison of normal fuels it actually matters little whether the 50 per cent. temperature or the dew point (65 per cent. temperature) is taken.

In connection with the fourth conclusion referred to above, relating to the heating of venturis for the prevention of ice, it should be pointed out that electrical heating was used for the experimental engine. The current required, however, appears to be on the high side for an aircraft installation. The use of oil heating for carburettors is to be recommended, as by this means the necessary supply of heat is provided during and after a sustained glide when intake air pre-heating from exhaust pipes would be quite ineffective and due to the high induction depression the tendency to form ice is increased. It is, in fact, these conditions which are likely to be the most dangerous, particularly if a long approach glide to an aerodrome is made and instant response to the throttles is essential in the event of the pilot needing additional control when landing.

Whatever means of heating is adopted, however, warning of the approach of dangerous conditions will be given by a suitable thermometer in the induction pipe since ice can only form at temperatures below 0°C. For those installations on which provision is made for temperature control of the mixture, such an instrument is of particular benefit and should be an essential part of the engine equipment. The electrical resistance bulb type of thermometer is the most suitable for the purpose.

Although, as already stated, the latent heat of evaporation of gasolines varies very little, that of benzol and alcohol is appreciably different, viz. :—

Fuel.	Latent Heat of Evaporation.	Boiling Point.
Aviation gasoline ...	140 B.Th.U.'s/lb.	55/160°C.
Motor benzol ...	170 ,,	75/140°C.
Ethanol	406 ,,	78°C.
Methanol	500 ,,	66°C.

The increased tendency to ice formation with benzol is therefore explained, as in addition to its high latent heat of evaporation it tends also to lower the dew point of the resultant blend (compared with the basic gasoline) with equivalent improvement in evaporating qualities.

Although the latent heat of evaporation of alcohol is very much greater than that either of gasoline or benzol, it does not have the effect of increasing ice formation for the reason that it is highly soluble in water and the freezing point of a mixture of alcohol and water is considerably below that of the water alone. It is indeed a fact that when ice has formed in an induction system it can be reduced by adding a comparatively small proportion of alcohol to the fuel. The effect appears to be that some of the alcohol deposits on the surface of the ice and reduces the freezing point with the result that the mixture melts. This mixture is carried away by the air/fuel stream and more alcohol is deposited, so that the process is continuous until all the ice is removed.

(*d*) *Specifications*

Specifications for boiling range of aviation gasolines have largely been built up as a result of experience by engine operators in collaboration with the fuel suppliers, and it is interesting to observe the requirements of the three main government specifications in use to-day:—

	U.S. Army Y-3557-G.	British Air Ministry D.T.D. 224 & 230.	French Air Ministry Norme, Air 3402.
Recovery to 75°C.	Not less than 10%	Not less than 10%	10 to 20%
,, 100°C.	,, 50%	,, 50%	Not less than 50%
,, 135°C.	,, 90%	Not specified	Not specified
,, 150°C.	Not specified	Not less than 90%	Not less than 90%
End point ...	,, ,,	Not to exceed 180°C.	Not to exceed 180°C.

The dew point of any fuel meeting these specifications is unlikely to exceed 115°C., whilst the limits laid down for the early part of the boiling range are adequate to ensure good starting.

Vapour Pressure

The formation of vapour in a fuel system occurs when the vapour pressure exceeds the liquid pressure. Thus the vapour pressure of a fuel becomes a characteristic of importance since every fuel system will have a limit to the quantity of vapour it can contain and yet maintain the requisite flow of fuel to the engine.

The vapour pressure of gasolines is generally measured for commercial purposes by the Reid method and is expressed in terms of " lbs./square inch at 100°F." Although related[29] to the boiling range, vapour pressure must be considered independently, as gasolines can be blended to meet the boiling range requirements of the chief specifications and yet possess vapour pressures which would be too high for safe use in an aircraft installation. Reference to Appendix No. 5 will show that most specifications lay down a maximum limit for vapour pressure as determined by the Reid apparatus of 7lbs./square inch at 100°F. (0.47 atm. at 37.8°C.). There should be no difficulty in designing fuel systems to operate satisfactorily under all conditions with fuels meeting this requirement, although the design of fuel systems to use motor spirits presents greater difficulties as these normally have higher vapour pressures than aviation gasolines (Fig. 29).

Flying conditions have a considerable influence on the formation of vapour from the fuel as shown in Fig. 30. Even more important is the design of the fuel system to avoid the accumulation of the vapour which is formed to cause a " lock." The essential features are the layout of the fuel lines, cocks, filters, etc., whilst the shape and internal roughness of all passages including the jets and the rate of fuel flow are equally important.

With engines fitted with fuel pumps which exert a suction head on the fuel line, the tendency to form vapour in the system is increased. An equally un-

[29] See page 907.

favourable feature of such installations is the fact that the fuel pumps are generally engine driven and consequently are exposed to a good deal of conducted heat, some of which will be transmitted to the fuel. It must also be remembered that duplication of fuel pumps may not provide the factor of safety at first apparent if they are connected to a common suction line.

In the case of installations in which trouble from vapour locking occurs, the advantage to be gained by providing additional cooling to the fuel lines, filters and pumps must always be remembered. "Venting" of pockets in lines or filters may be employed when it has been found they are responsible for the accumulation of vapour. An increase in head or rate of flow may also avoid the collection of sufficient vapour to cause locks.

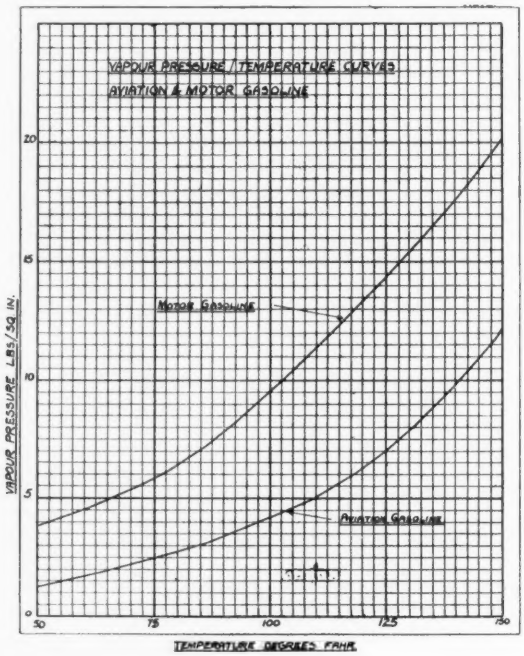


FIG. 29.

Some comprehensive work has been done on the subject of vapour locking of fuel lines by Dr. Oscar Bridgeman and his collaborators of the U.S. Bureau of Standards. This work has been described in various papers[30 to 33] and has included a large number of full-scale experiments on the measurement of fuel line, tank and carburettor temperatures in numerous types of aircraft.

The subject of vapour locking would be incomplete without some reference to the possibility of these occurring through the liberation of dissolved air in the

[30] Airplane Fuel Line Temperatures, by Oscar C. Bridgeman, Hobart S. White and C. A. Ross. S.A.E. Journal, Vol. 26, August, 1931.

[31] The Effect of Airplane Fuel Line Design on Vapour Lock, by Oscar C. Bridgeman and Hobart S. White. S.A.E. Journal, Vol. 25, October, 1930.

[32] Vapour-Locking Tendency of Aviation Gasolines, by Oscar C. Bridgeman and Hobart S. White. S.A.E. Journal, Vol. 25, August, 1930.

[33] The Effect of Weathering on the Vapour-Locking Tendency of Gasolines, by Oscar C. Bridgeman and Elizabeth W. Aldrich. S.A.E. Journal, Vol. 26, July, 1930.

fuel. Fuel which has received considerable agitation during the process of filling the tanks of a machine may contain sufficient air to cause a lock when it is released at the lower atmospheric pressures at altitude. This can be avoided by re-design of that part of the fuel system at which the air is first able to collect and whence the ultimate restriction of flow or possibly complete lock originates.

Freezing-point

The first stages of freezing of gasoline are indicated by the formation of minute crystals of ice in the liquid. These crystals appear at appreciably higher temperatures than the ultimate freezing of the bulk of the liquid.

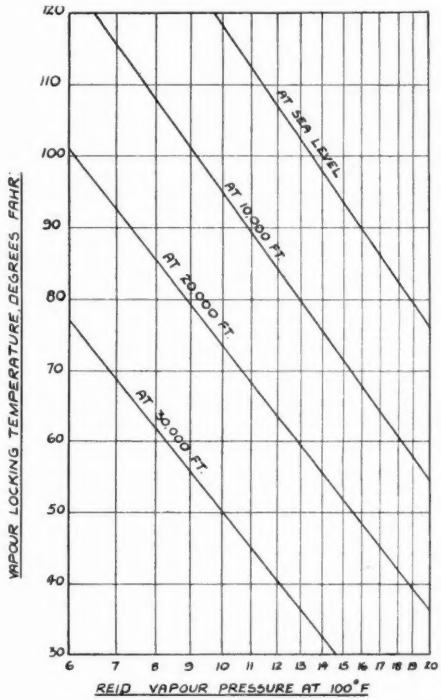


FIG. 30.

The effective freezing point of an aviation gasoline is taken at the temperature at which crystals are first detected, as it is possible in practice that these may accumulate in a filter to such an extent that they would obstruct the fuel flow long before the temperature became sufficiently reduced to cause solidification of the bulk of the fuel in the tank or pipe lines.

Reference to the most important specifications for aviation gasoline indicates that a maximum freezing point of $-50°C.$ provides an adequate safety margin, and this figure is easily met by all fuels entirely of petroleum origin.

With benzol mixtures, however, the case is different, as pure benzene has a freezing point of $+5°C.$ and the average " motor benzols " used for blending in aviation fuels have freezing points of about $-10°C.$ In Fig. 31 a freezing point curve for mixtures of aviation gasoline and benzol is given from which it will be seen that if $-50°C.$ is regarded as the safe limit, it is not possible to

employ any blend containing more than 20 per cent. of benzol. The benzol used in this case had a freezing point of −10°C.

Toluene can, of course, be used in place of benzol in much larger quantities if a product of the necessary purity can be obtained, the freezing point of pure toluene being −95°C.

Although the alcohols normally used in blends of gasoline have extremely low freezing points, one of the chief dangers attached to their use is their tendency to separate from the gasoline at low temperatures. This characteristic is dependent upon the water content of the alcohol, as shown in Fig. 32.

It will also be observed that the addition of benzol to alcohol/gasoline blends is of some advantage in reducing the tendency to separation.

For comparatively limited concentrations of alcohol, it will be seen that separation occurs very readily when only extremely small quantities of water are present.

Due to this extreme sensitivity to separation and their lower calorific value, alcohol fuels are considered by most authorities to be unsuitable for regular air line use.

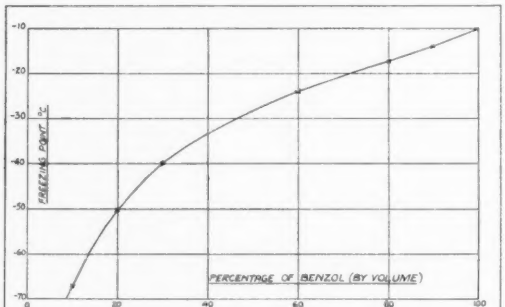


FIG. 31.

Specific Gravity

Relatively the specific gravity of aviation gasolines is of little interest compared with other properties, as evidenced by the wide range which is permitted in the principal specifications (see Appendix No. 5).

The fuel level in the float chamber depends upon the specific gravity, and thus will have an effect on the fuel flow from the jet by virtue of the alteration of head. The extent of this will depend upon the position of the jet, *i.e.*, whether it is free or submerged, the former being the more sensitive. Most modern carburettors are designed with submerged jets and with these the variations in specific gravity of aviation gasolines (about 0.710 to 0.765) produce an insignificant variation in flow.

From the point of view of aircraft performance, specific gravity is also important, as it controls the total fuel weight for a given tank capacity. Considered on a weight basis alone the maximum variation in the heat value of normal aviation gasolines of different specific gravities amounts to less that 3 per cent. in favour of the low specific gravity fuels. On a volume basis, however, the difference will amount to 4 per cent. for aviation gasolines in favour of the high specific gravity fuels. It is only when the extreme range of aircraft is being considered that figures of this magnitude are of any interest, and even then other properties of the fuels are likely to have a far greater influence on performance.

Viscosity

The flow of liquid through a jet is directly proportional to its coefficient of discharge, and this in turn depends upon the viscosity of the liquid, the shape, size and length/diameter ratio of the jet.

In the case of carburettor jets the arrangement of them, *i.e.*, whether free or submerged, is also important. The extent to which the viscosity affects the coefficient of discharge also depends upon the design of the jets, so that in some

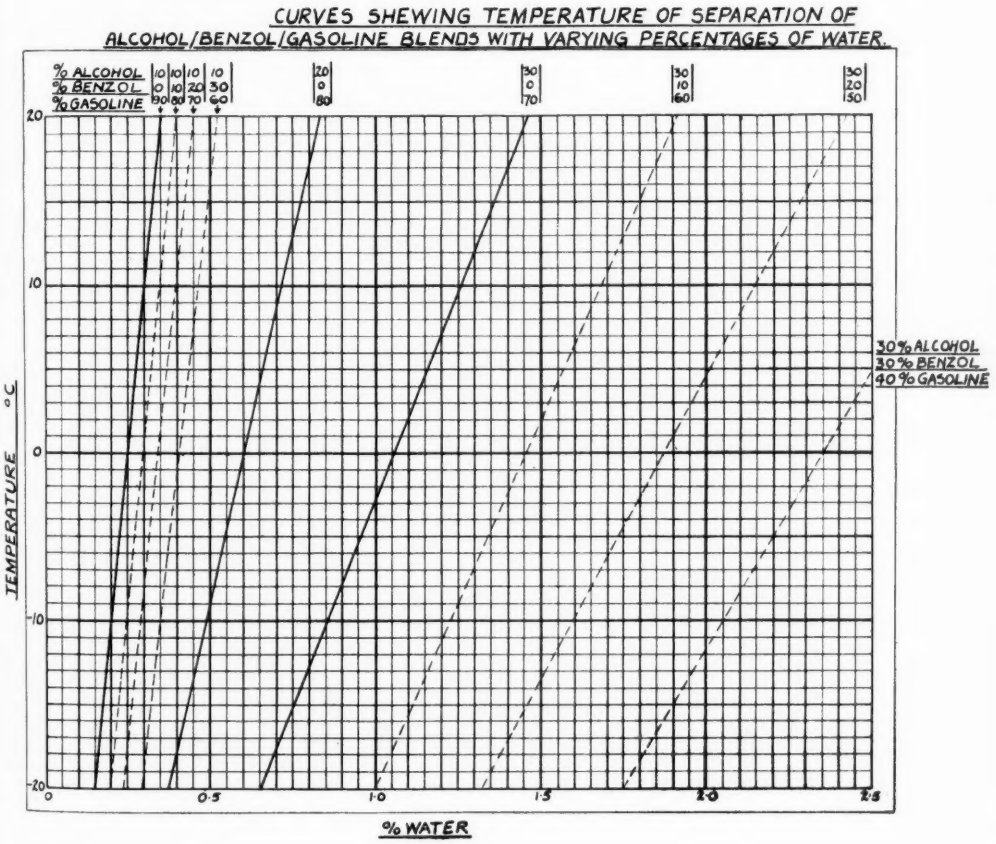


FIG. 32.

cases a change in viscosity over the range which is met in practice will be insignificant, whilst in others it will cause variations in mixture strength at certain rates of flow.[34] As fuel viscosity is related to temperature, it is obvious that carburettors should be designed primarily to be independent of fuel viscosity since the variations met in service, due to changes of temperature, are greater than those of different basic gasolines.

[34] Carburettor Fuel Metering Characteristics, by W. C. Clothier, M.Sc., Wh.Sch. R. & M. No. 1361.

Gasoline viscosities range from about 0.40 centipoises to 0.50 centipoises at 30°C. and with the majority of modern carburettors this is insufficient to effect any appreciable variation in mixture strength.

Calorific Value

The extent and effect of variations in the heat value of gasolines has already been referred to in the notes on specific gravity. For a given viscosity and specific gravity, the supply of heat energy to an engine from a carburettor will vary directly as the calorific value. Actually, changes in calorific value in gasolines are invariably attended by changes in specific gravity and viscosity, so that it is impossible to generalise on the possible effects of these variants on the flow characteristics of carburettors.

When other types of fuels are considered, more striking differences in calorific value are observed, viz. :—

Fuel.	Specific Gravity @ 15° C.	Gross Calorific Value. B.Th.U's/lb.	B.Th.U.'s/Imp. Gall.
Gasoline	0.704/0.782	19,500/20,100	142,000/152,250
Benzene (pure) ...	0.884	18,250	157,000
Methyl alcohol ...	0.829	9,900	82,100
Ethyl alcohol ...	0.794	11,800	94,500

Blends containing alcohol, therefore, will require special carburettor adjustment to compensate for their reduced calorific value. For the same reason, for a given fuel load, the range of aircraft using alcohol fuels will be reduced.

Impurities

(*a*) *Water*

Gasoline itself is non-hygroscopic and will separate completely from water with which it may be mixed.[35]

With normal care it is possible to deliver gasoline into the tanks of an aircraft virtually free from water, any quantity which may be held in suspension being insufficient to cause trouble if the usual design of tanks and filters is employed.

In large storage tanks water may remain in suspension in the gasoline for some time after they have been filled. The process of filling the tank causes agitation of any water lying in the bottom of the tank and admixture of it with the gasoline. Therefore it is desirable that after such a tank has been filled, supplies should not be drawn from it within an hour or two unless the very greatest care is taken in filtering. Water can usually be detected in tanks by the use of water-finding paper.

The paper used for the detection of water in gasoline tanks is usually coated with coloured sugar solution which is dissolved on contact with the water so that a clear mark is left on the paper at the water level in the tank.

(*b*) *Gum*

Various tests are embodied in the most important specifications for the purpose of eliminating fuels of high gum forming characteristics. As a general rule such tests are only necessary when benzol, cracked or coal spirit products are included in the fuel, as the straight run petroleum aviation gasolines have a practically negligible gum content as determined by the tests laid down in the chief specifications.

The gum tests may be divided into two classes, viz., those for the estimation of existent gum, and those for the estimation of potential gum. The latter test is taken as an indication of the stability of the fuel for storage purposes. The normal test for existent gum which is adopted in most European specifications consists of evaporating a given quantity of fuel to dryness

[35] Water is soluble in gasoline to the extent of about 0.01 per cent. only.

in a glass dish by maintaining it at 100°C. The resultant residue is thus determined as a percentage of the fuel evaporated. The accelerated ageing test given in the American specifications is essentially a potential gum test and requires a fuel first to be put in a bomb containing oxygen at 100lbs./square inch and maintained thus at a temperature of 100°C. for four hours. The sample is then evaporated to dryness in a glass dish and the weight of the gum residue determined in the usual way. A potential gum test is also included in the D.T.D. 224 and D.T.D. 230 specifications. In this case the fuel is incubated at 35°C. for 20 hours before making the usual gum determination.

(*c*) *Sulphur*

It is necessary that in all fuels there should be a complete absence of free sulphur, but total sulphur contents of up to 0.15 per cent. are admitted in various specifications. The total sulphur contents of the best aviation gasolines do not usually exceed 0.05 per cent., and it is only when benzol and coal spirit blends are employed that there is any risk of the sulphur content approaching the limits laid down in the various specifications.

Corrosive acids resulting from the admixture of products of combustion of the sulphur with water vapour (H_2SO_3 and H_2SO_4) are only harmful when condensed, a condition which is seldom met in practice, except during starting and warming up and when the engine is cooling down. In any case, the lubricating oil film on most working parts provides adequate protection from the small quantities of corrosive materials which may develop. There is some evidence that a high sulphur content produces excessive corrosion of sparking plug electrodes, but this can be overcome by the use of suitable electrode materials.

Special Tests

Acid Heat Test

The general trend is for aviation gasoline specifications to become simplified now that the practical influence of the main physical characteristics of them are understood. Therefore, few special tests are to be found included in modern specifications.

With the introduction of the C.F.R. motor method as the standard for testing aviation gasolines in America, it was thought that it gave too favourable a rating for some cracked gasolines, benzol and alcohol. To exclude such fuels which might otherwise pass all other requirements of the specification, an acid heat test was devised. This test consists merely of mixing 150 mls. of gasoline with 30 mls. of pure sulphuric acid, and after agitation the temperature rise recorded. The temperature rise must not exceed 11°C. according to the American specifications incorporating this test.

Future Developments

With the introduction of new methods of refining and synthesis in the petroleum industry it is not altogether certain that fuels of the future will retain their identities as they are known at the present time. The increasing demand for fuels of high octane number becomes more and more difficult to satisfy if existing specifications are to be adhered to. The inclusion of cracked fuels in aviation gasolines is likely to be of some benefit from the production point of view, and with improved methods of refining it is probable that such fuels will be made available which will meet the demands of the aviation industry in regard to stability, freedom from gum formation and anti-knock value. Nevertheless, the use of these fuels for aviation must lead to some modification of existing specifications.

Attention has also been drawn to the commercial production of iso-octane, and although the quantities of this product, which are likely to be available for some time to come, will be extremely small, it is of interest to examine its possible

influence as a blending agent in aviation gasolines. Further research in the petroleum industry may lead to the synthesis of other very high knock-rating compounds, but the production of these on any commercial scale cannot be envisaged at the present time.

Iso-Octane

Pure iso-octane (2-2-4 tri-methyl-pentane) has the following properties and the commercial product is unlikely to have very different characteristics :—

Specific gravity at 15°C.	...	0.694
Boiling point	... ...	99.3°C.
Freezing point	... ...	−100°C.

(*a*) *Anti-Knock Value*

By definition of the terms of reference at present used for the expression of anti-knock value, iso-octane has an octane number of 100. This is, however, purely an arbitrary standard, and it is possible that with the introduction of fuels of anti-knock values of this order a new scale or standard will have to be adopted. For the time being the anti-knock value of fuels of more than 100 octane number can be obtained by extrapolation.

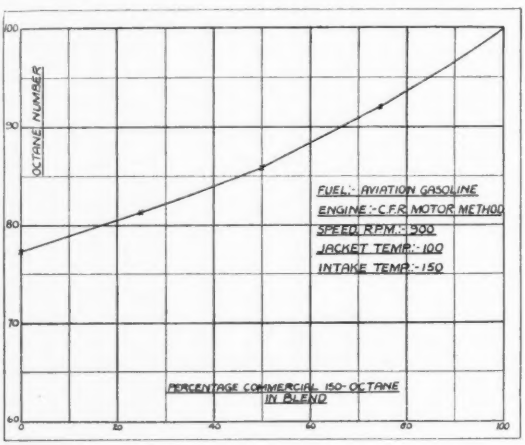


FIG. 33.

Whatever blends of aviation gasoline and iso-octane may be used, it is certain that tetra-ethyl lead will be used still further to increase their anti-knock value. In Figs. 33 and 34 the anti-knock value of blends of aviation gasoline and iso-octane are shown together with their respective lead curves. It is clear from these curves that fuels of 100 octane number and over can be obtained with normal concentrations of tetra-ethyl lead. It is also interesting to observe that with straight blends of iso-octane and aviation gasoline up to 50 per cent. the blending value of octane is only 95.

A word of caution should be given in the interpretation of the results obtained with these very high anti-knock value fuels. The exact determination of their octane numbers presents some difficulty, as the accuracy of the C.F.R. engine diminishes appreciably in that range. Secondly, there is no evidence available to show whether or not the C.F.R. results can be relied upon to give satisfactory correlation with full-scale engines within this range. For example, the addition

of 3.6 ccs. T.E.L./imperial gallon to pure octane produces an increase in octane number of just over six, whereas the increase in the aviation gasoline for a similar amount of lead is nearly twelve octane numbers. This may only be a characteristic of the C.F.R. engine, and only further research on it and full-scale engines can show whether new methods of testing will have to be developed for these high anti-knock value fuels.

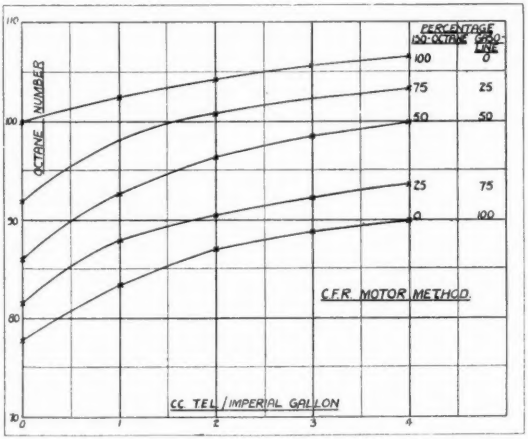


FIG. 34.

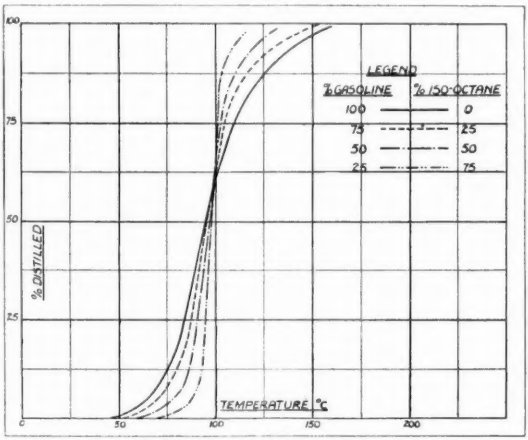


FIG. 35.

(*b*) *Boiling Range*

The distillation curves for three blends of octane and aviation gasoline are shown in Fig. 35. The effect of the octane in reducing the volatility at the lower end of the boiling range is shown. It will be noticed that to meet the existing specifications the quantity of octane that could be used is limited. This is a difficulty which will doubtless be overcome in the future, either by adjustment of

the boiling range of the gasoline constituent, or, more likely, by the development of engine starting systems to cope with the decreased volatility at low temperatures. From the point of view of distribution efficiency, which can be judged by the percentage recovered to 100°C. in the distillation test, the addition of octane to existing aviation gasolines actually results in an improvement.

(*c*) *Vapour Pressure*

Fig. 36 shows that the addition of octane to aviation gasoline has the effect of reducing the vapour pressure as determined by the Reid apparatus at 100°F. This leaves a margin, should occasion arise, for the readjustment of the boiling range to compensate for the lower initial volatility of octane/gasoline blends.

However, the specification and octane concentrations to be used in the fuels of the future will depend too much on economic and practical considerations to anticipate them at the present time.

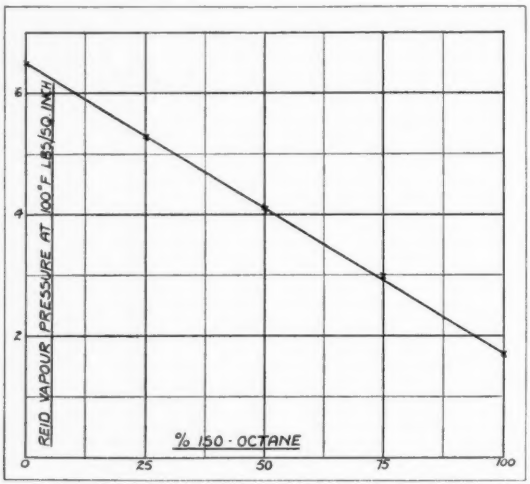


FIG. 36.

In conclusion, the author wishes to express his thanks to the Directors of the Asiatic Petroleum Company for their permission to publish this paper and also his indebtedness to his colleagues in the Asiatic Petroleum Company and the Amsterdam and Delft Laboratories of the Bataafsche Petroleum Maatschappij for their valuable help in the preparation of the paper.

Acknowledgment is also due to the Air Ministry and the Bristol Aeroplane Company for their assistance in providing data which has been incorporated in the paper.

APPENDIX NO. I

The improvements in power output that can be obtained by using high octane fuels in suitably designed engines are already well known and the object of this appendix is merely to give an indication of the possible improvements in operating costs that can be effected by using such fuels.

It is obvious that the advantages to be gained by employing fuels of higher anti-knock values will vary considerably according to the type of aircraft in which

they are used, the improvement depending on the ratio of pay load to engine weight and fuel load.

In the case of a machine in which the engine weight is high compared with the fuel load, it will be preferable to use supercharge in order to decrease the specific weight of the engine. Fig. 1 shows how specific engine weight can be reduced by using high octane fuels, due allowance being made for the increase in gross weight necessitated by the higher maximum pressures obtaining with the increased boost pressures. In the case of machines in which the fuel load is

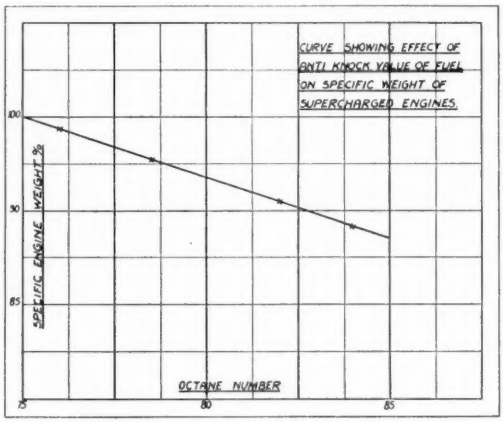


FIG. 1.

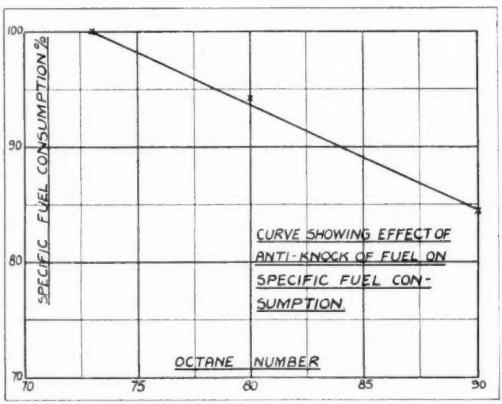


FIG. 2.

high, it will be preferable to reduce the fuel consumption by increasing the compression ratio; the reduction which can be obtained is shown in Fig. 2.

From the above remarks it will be seen that the way in which the engine is modified to take full advantage of the high octane fuels will depend on the range of the aircraft. Fig. 3 shows how the weight of the engine, fuel, etc., can be

reduced by (1) increasing the compression ratio, and (2) using boost, at various ranges. In actual practice, of course, it would probably be preferable both to increase the compression and to use a certain degree of supercharge.

If the engine and fuel weight is reduced by using high anti-knock fuels, then for a given all-up weight the pay load can be increased. Fig. 4 shows the increase in pay load that can be obtained on two widely different classes of aircraft by the use of high octane fuels; for purposes of comparison, the increase in pay load has been reckoned on a basis of the allowable increase in the cost of the fuel, *i.e.*, the increase in fuel cost that could be tolerated without an increase in the ratio of fuel cost to pay load receipts. Line 1 on Fig. 4 shows the advantage to be gained by increasing the compression ratio of the engines of a

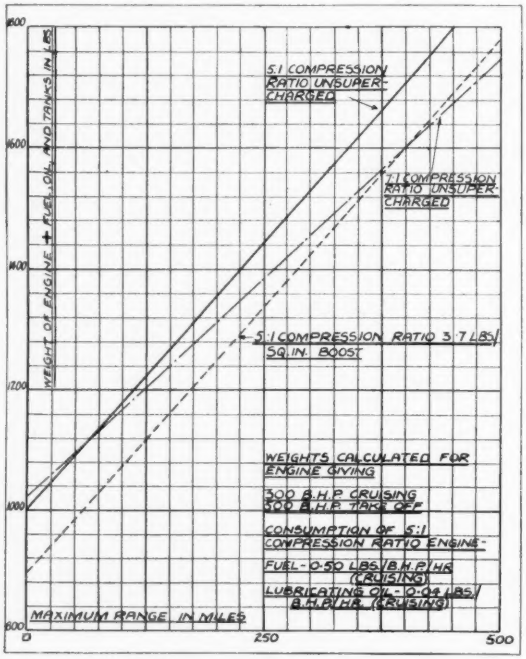


FIG. 3.

long-range flying boat, so as to make the fullest use of the high octane fuels. Line 2 shows the advantage to be gained by using the maximum amount of supercharge obtainable on the high octane fuels in a short-range high-speed machine.

For the purposes of these calculations it was assumed that the cost of 73 octane fuel was 1s. 8d. per gallon and that of 80 octane was 1s. 9d. per gallon. The pay load receipts were reckoned on a basis of £0.18 per ton mile, a figure which is based on the hypothetical operating costs of an economical machine flying 200,000 miles per annum.

All calculations are based on the published figures for actual aircraft, and no allowance was made for the advantages which would obviously be gained by the reduced frontal area of the engines using high octane fuels.

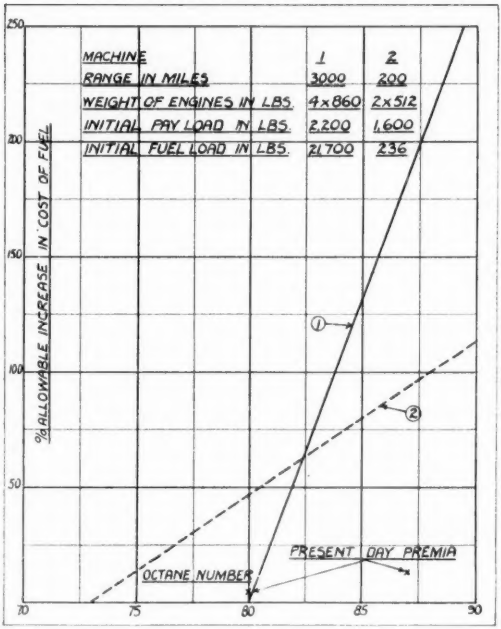


FIG. 4.

APPENDIX NO. 2

Extract from Airworthiness Handbook for Civil Aircraft

PART I.—AEROPLANES.

DESIGN LEAFLET C.2.

Engine Requirements—Engine Tests.

General.

Paragraph 52. *Detonation Tests.*

(i) Prior to type test, a detonation test must be carried out to confirm that the rating of the engine is satisfactory under the conditions of " take-off " speed and throttle opening when installed in the aircraft, on the fuel specified for the type test (see paragraph 55).

(ii) For the purpose of this test it will be assumed that the standard " take-off " speed is 95 per cent. of the International or Special r.p.m. for engines rated at full throttle at sea level and for engines rated at an altitude (whether super-compression or supercharged) the take-off speed will be calculated from the following formula :—

$$\text{Take-off speed} = \{ .95 \sqrt[3]{(\text{g.t.p./f.t.p.})} \} N^3$$

where g.t.p. is the " gated throttle power " at sea level, f.t.p. is the calculated " full throttle power " at sea level and International or Special r.p.m., and N is the International or Special r.p.m. (The calculated full throttle power at sea level is the International or Special power divided by the standard " height power factor " for the rated altitude—see Leaflet C.4.)

(iii) (*a*) For engines rated at sea level, the detonation test will be run in a similar manner to the power curve (see paragraphs 36 to 39), and observation made (by an approved method) of the engine speed at which detonation occurs to the degree or standard agreed by the Secretary of State for the particular design of engine.

(*b*) For super-compression or " gated throttle engines " the detonation test will be run in a similar manner to the " gated throttle curve " (see paragraph 48).

(*c*) For supercharged engines rated at an altitude the detonation test will be carried out in a similar manner to the maximum permissible boost curve (see paragraph 47).

(iv) Should the speed at which the agreed degree of detonation occurs be higher than the calculated " take-off " speed, it may be necessary for the constructor to modify the engine, or the rating, or specify a higher grade anti-detonation fuel in order to reduce the detonation to the necessary standard at or below the calculated " take-off " speed.

(v) If, however, the constructor is of opinion that the agreed standard of detonation is too low, and that the particular design of the type engine will satisfactorily withstand in service the degree of detonation demonstrated by the detonation test at the calculated " take-off " speed, he may proceed with the type test, the last period of the endurance test of which is required to be run under the conditions of " take-off " speed and power. If, therefore, the condition of the engine at the conclusion of the type test is satisfactory the higher degree of detonation will be accepted.

(vi) All detonation tests will be carried out as far as possible under atmospheric conditions of standard sea level, and consideration will be given to the effect of unavoidable variation from these conditions.

(vii) The fuel used must be the same as that specified for the type tests and the mixture strength will be that provided by the proposed flight size of jet in the carburettor, the mixture or altitude controls being in the fully rich position.

(viii) The compression ratio of the cylinders which satisfactorily pass the detonation test will be the maximum limit for subsequent series engines, any plus tolerance necessitating a repetition of the detonation test unless otherwise agreed by the Secretary of State.

PART I.—AEROPLANES.

DESIGN LEAFLET C.3.

Engine Requirements—Tests for Engines Rated for Performance at Sea Level.

Paragraph 9. *Endurance Test.*

(i) An endurance test of 50 hours' duration will then be run in five non-stop periods of ten hours each. The first twenty hours of this test must be run on an approved form of brake at nine-tenths of the International power and at International r.p.m. in accordance with paragraph 34 of Leaflet C.2.

(ii) Twenty hours of the test must be run as a thrust test, an airscrew calibrated to absorb approximately nine-tenths of the International power at International r.p.m. and to give a thrust of approximately $4\frac{1}{2}$ pounds per h.p. being used for this purpose (see Leaflet C.2, paragraph 49).

(iii) Nine hours of the last ten hours' period must be run at full throttle on an approved form of brake at the calculated " take-off " speed of the detonation test, paragraph 52 (ii) of Leaflet C.2, and at the commencement of the last hour, the speed must be adjusted so that the engine continues to run at full throttle but at International r.p.m.

Appendix No. 3

Summary of "The Knock-Rating of Aviation Fuels," by D. R. Pye, M.A., Chairman, Sub-Committee on Knock-Rating of Aviation Fuels, Institution of Petroleum Technologists. (Proceedings of the World Petroleum Congress, London, 1933, Volume II.)

The paper gives the results of detonation tests upon nine different aviation fuels when compared with a sub-standard of which the knock-rating was varied by the addition of tetra-ethyl lead. The nine samples were matched against the sub-standard in water-cooled and air-cooled aircraft engine cylinders and also under a variety of conditions in the Series 30 and C.F.R. test engines. An extremely high level of consistency was achieved as between the different aircraft engine tests and among the test engines in different laboratories.

It is now recognised that two fuels which show the same anti-knock characteristics when tested under certain conditions may exhibit a marked difference under other conditions. The most important difference between the operating conditions as they affect the fuel are the cylinder and gas temperatures throughout the engine cycle. A rise of the average cycle temperature always promotes

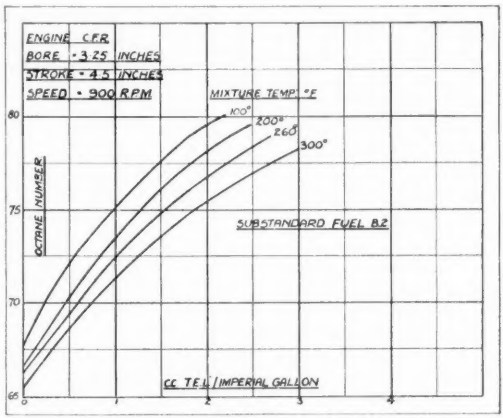


FIG. 1.

detonation with all fuels; but the degree to which fuels react to an increase of temperature differs widely. It will be apparent that a rise in cycle temperature can be produced by increasing the mixture temperature; Fig. 1 shows how a gasoline containing various proportions of tetra-ethyl lead is depreciated by increased mixture temperatures; the knock-rating was determined by direct comparison with octane/heptane mixtures. It is a point much in favour of the mixtures of iso-octane and heptane for use as an ultimate standard, that changes of cycle temperature affect their detonation characteristics less than any known fuel commercially available. The fuels most adversely affected are those containing a large proportion of benzene.

The results of the aircraft engine tests fall into two categories, the one containing the water-cooled cylinder results and the normally aspirated air-cooled cylinder results, while in the second category were the results in the supercharged air-cooled cylinder and with an air-cooled cylinder of an exceptionally high compression ratio.

It is concluded that the C.F.R. is the most suitable test engine and that good correlation with the results obtained upon the aircraft engine cylinders can be achieved without going above 900 r.p.m. or 212°F. jacket temperature. For the aircraft engine results in the first category given above the best correlation was given by the C.F.R. engine with a mixture temperature of 100°F. For the second category a mixture temperature of 260°F. gives the better correlation.

The range of octane numbers covered by the fuels tested did not go above 75 according to the proposed method of test or 80 according to the less severe conditions investigated. Moreover, none of the fuels contained spirits derived from cracking processes and no alcohol blends were included. It is suggested, however, that since some of the fuels tested contained large percentages of aromatics, it is not likely that any fuels containing cracked spirits which would be accepted for aviation purposes would be likely to be depreciated, as compared with the sub-standard, to a greater degree than any of the fuels used. It is concluded, therefore, that the use of the C.F.R. engine at a speed of 900 r.p.m., with a jacket temperature of 212°F. and a mixture temperature of 260°F. should afford a satisfactory means of rating aircraft fuels.

Tests at Royal Aircraft Establishment.

The engine was run at full throttle either normally aspirated or with an intake heated to 50°C., zero boost to simulate supercharged conditions at 12,000 feet. Mixture strength was adjusted for maximum detonation (equivalent to maximum power for the water-cooled engine, 96 per cent. maximum M.E.P. for the air-cooled engine). The speed was then increased until audible detonation ceased; that at which detonation ceased was used as the criterion for matching with the sub-standard fuel B.2 plus tetra-ethyl lead under similar engine conditions, *i.e.*, the engine was operated on sub-standard fuel at speed at which detonation ceased on fuel to be rated—if this speed was within ± 50 to 30 r.p.m. of speed at which detonation ceased on the sub-standard the match was considered satisfactory.

Tests at Bristol.

In these tests, the audible method was again used to detect detonation. On the normally aspirated engine, the unit was throttled to the point of incipient detonation at constant speed, and constant fuel consumption at normal full load figure. On the supercharged unit, supercharge was increased to the point of incipient detonation under constant speed and fuel consumption conditions. Again the fuel was matched against sub-standards, throttle opening or degree of boost being used as the criterion for matching.

Appendix No. 4

The C.F.R. Engine.

The Standard Co-operative Fuel Research engine is manufactured by the Waukesha Motor Company of Wisconsin.

The principal constructional features can be clearly seen in Figs. 1 and 2. The leading dimensions of the engine are:—

Bore	...	...	...	3.25 inches (82.6 mm.).
Stroke	...	...	...	4.500 inches (114.3 mm.).
Swept volume	...	...		37.4 cu. inches (614 ccs.).
Speed	...	...	...	900 r.p.m.

The compression ratio can be altered while the engine is running by raising or lowering the complete cylinder block relative to the crankshaft; and a special

compensating valve rocker gear maintains the valve clearances at a pre-determined figure irrespective of the compression ratio. Evaporative cooling is employed as providing a simple means for maintaining the cylinder jacket temperature constant and distilled water is used in the cylinder jacket to obviate scale deposition. A 1 kilowatt heater is fitted in the induction pipe in order to maintain the mixture at the required temperature. At present a four-bowl carburettor with four gravity tanks is used; in this carburettor, fuel can be fed from any of the four float chambers to a single jet in the choke tube; the mixture strength is controlled by means of an air bleed which delivers air to the choke

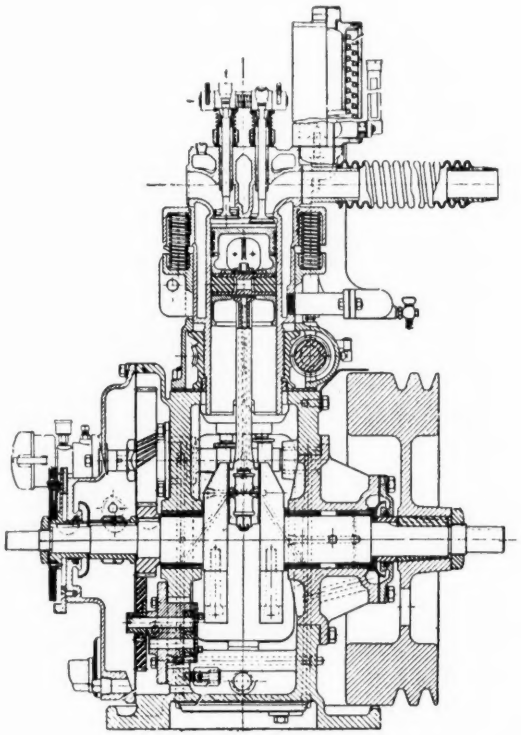


FIG. 1.

tube diametrically opposite to the fuel jet. There are separate air bleed adjustments for each float chamber and a single valve opens the corresponding air bleed and fuel passage for one float chamber. With this arrangement, when once the mixture strength is set for a given fuel, the change over from one fuel to another is affected by a single movement of the valve and the mixture strength requires no further adjustment.

Ignition timing is varied automatically with the compression ratio and is set at approximately 10° earlier than that required for maximum power.

The degree of knock is recorded by means of a Midgley bouncing pin indicator which is fitted vertically into a pocket in the cylinder head diametrically opposite to the sparking plug. The bouncing pin mechanism consists of a light steel diaphragm which is exposed to the gas pressure in the cylinder head and

which is deflected slightly by the extreme pressures which occur under detonating conditions. The movement of the diaphragm is transmitted by a light steel pin to the lower of a pair of contacts, so arranged that when deflection of the diaphragm occurs owing to detonation the contacts are closed and current is allowed to pass through a wire resistance. The time during which the contacts remain closed and therefore the temperature of the wire resistance, is a function of the intensity of detonation. The temperature of the wire resistance is measured by means of a thermo-couple and is recorded by a galvanometer which

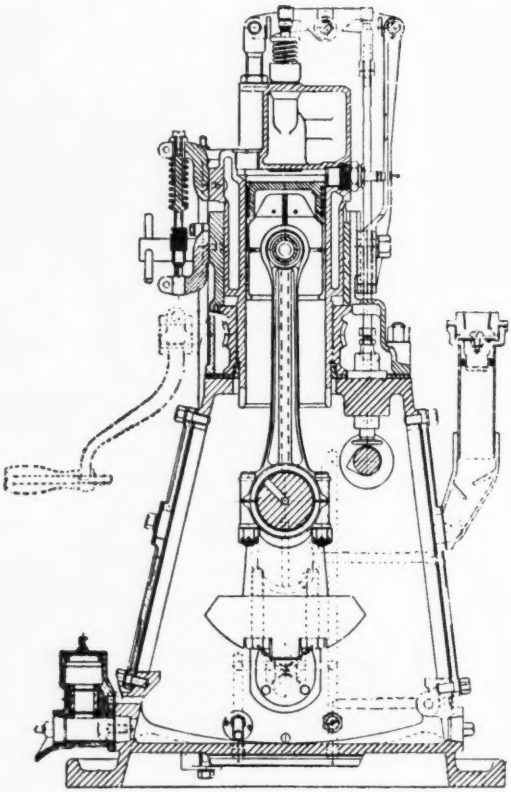


FIG. 2.

is termed a " knock meter," which has a purely arbitrary scale inscribed upon it reading from 0 to 100.

The anti-knock values of fuels are measured in the C.F.R. engine by determining the proportions of a mixture of iso-octane and normal heptane which corresponds in anti-knock value to the fuel under test.

Owing to the high cost of the pure standard fuels, sub-standard reference fuels are normally used in practice. Usually a specially prepared gasoline of comparatively low anti-knock value is taken as the basic fuel, those supplied by the Standard Oil Development Company being universally known. The knock-rating of these can be raised either by the addition of pure benzene or tetra-ethyl

lead, and in either case it is necessary to calibrate them against blends of octane and heptane so that results obtained with the sub-standard fuels can be readily translated into "octane numbers." Typical calibration curves are shown.

Knock-rating determinations are made on the C.F.R. engine by the following method. To ensure adequate stabilisation of temperatures it is necessary to warm up the engine for an hour before undertaking any tests. The jacket temperature must be maintained at 100°C. within plus or minus 2°C., and remain constant during the test to within 0.6°C. The mixture temperature must be maintained within plus or minus 1.1°C. of the figures specified, *i.e.*, 149°C. for the "motor method," and 126.7°C. for the "modified motor method" or "aviation method." Exact temperature control both of the engine and the room in which it operates is very necessary, owing to the extreme sensitivity of the engine to temperature variations. When steady temperature conditions have been obtained the engine is run on the fuel to be tested, the knock-rating of which is unknown. The compression ratio is increased and the mixture strength adjusted until at maximum detonation mixture strength there is a knock meter deflection of about 50 divisions. The compression ratio is maintained constant at this setting for the rest of the test. The exact knock meter deflection is recorded and the engine is then changed over to a blend of sub-standards which it is estimated will have an anti-knock value slightly inferior to that of the sample. The mixture strength is again adjusted for maximum detonation and the knock meter reading recorded. This procedure is repeated with a blend of sub-standards estimated to have an octane number slightly superior to that of the fuel under test.

From the knock meter deflections obtained on the two sub-standard fuels and also on the fuel under test, the octane number of the fuel to be tested is determined by a system of bracketing. The following illustrates the method employed:—

Fuel.	Knock-Meter Reading.
Test sample	48
First sub-standard blend (equivalent to 70 per cent. octane/30 per cent. heptane)	56
Second sub-standard blend (equivalent to 75 per cent. octane/25 per cent. heptane)	43

From these results it will be seen that a difference in knock meter deflection of 13 degrees corresponds to a difference in octane number of 5. The sample is better than the 70 octane sub-standard by eight knock meter divisions, so that the octane number of the sample can be calculated, viz.:—

$$\{ (8 \times 5)/13 \} + 70 = 73.$$

Sufficient experience has now been gained with the C.F.R. engine in routine testing in commercial laboratories to obtain some idea of its accuracy and repeatability. Engines working in the same laboratory should not give a spread of more than one octane number for determinations made on the same sample, but this spread may be increased to two octane numbers when comparisons are made between different laboratories. Even this degree of accuracy tends to diminish for the knock-rating determinations of fuels of more than 80 octane number.

APPENDIX No. 5

	British Air Ministry.	British Air Ministry.	French Ministère de l'Air.	French Ministère de l'Air.	U.S. Air Corps.
Number	D.T.D. 224	D.T.D. 230	Normes 3401 & 2 Aéronef A	Normes 3401 & 2 Aéronef B	Specification Y-3557/G
Specific Gravity ...	0.79 max.	0.79 max.	0.78 max.	0.78 max.	—
Boiling Range—					
10% Recovery ...	Below 75°C.	Below 75°C.	Below 75°C.	Above 75°C.	Below 75°C.
20% ,, ...	—	—	Above 75°C.	Below 75°C.	—
50% ,, ...	Below 100°C.	Below 100°C.	Below 100°C.	Below 100°C.	Below 100°C.
90% ,, ...	Below 150°C.	Below 150°C.	Below 150°C.	Below 150°C.	Below 135°C.
96% ,, ...	—	—	—	—	—
Final Boiling Point	180°C. max.	180°C. max.	180°C. max.	180°C. max.	—
Reid V.P. at 100°F.	7lbs./sq. in. max.	7lbs./sq. in. max.	0.5 kg./sq. cm. max.	0.5 kg./sq. cm. max.	7lbs./sq. in. max.
Total Sulphur ...	0.15% wt. max.	0.15% wt. max.	0.15% wt. max.	0.15% wt. max.	0.10% wt. max.
Actual Gum ...	10 mgms./100 cc. max.	10 mgms./100 cc. max.	6 mgms./100 cc. max.	6 mgms./100 cc. max.	—
Potential Gum ...	10 mgms. max. more than actual gum	10 mgms. max. more than actual gum	—	—	10 mgms./100 cc. max.*
Freezing Point ...	Below −50°C.	Below −60°C.	Below −45°C.	Below −45°C.	Below −60°C.
Maximum Lead Concentration	—	4 cc./I.G.	—	0.8°/00	6 cc./U.S. gal.
Minimum Octane Number	77	87	70	85	92 (nominal)
Method	C.F.R. modified motor method	C.F.R. modified motor method	C.F.R. modified motor method	C.F.R. modified motor method	C.F.R. specially modified†
Acid Heat... ...	—	—	—	—	—

	Pratt & Whitney.	Pratt & Whitney.	Wright Aeronautical Corporation.	Wright Aeronautical Corporation.	T.W.A.
Number	73 & 80	87	73 & 80	87	80 & 87
Specific Gravity ...	—	—	—	—	—
Boiling Range—					
10% Recovery ...	Below 70°C.	Below 70°C.	Below 75°C.	Below 75°C.	Below 75°C.
20% ,, ...	—	—	—	—	—
50% ,, ...	Below 90°C.	Below 90°C.	Below 105°C.	Below 100°C.	Below 100°C.
90% ,, ...	Below 110.5°C.	Below 110.5°C.	Below 180°C.	Below 135°C.	Below 155°C.
96% ,, ...	Below 122°C.	Below 122°C.	—	—	Below 180°C.
Final Boiling Point	—	—	—	—	—
Reid V.P. at 100°F.	Below 7.5lbs./sq. in.	7.5lbs./sq. in. max.	7.olbs./sq. in. max.	7.olbs./sq. in. max.	7.olbs./sq. in. max.
Total Sulphur ...	0.10% wt. max.	0.10% wt. max.	0.10% wt. max.	0.10% wt. max.	0.10% wt. max.
Actual Gum ...	—	—	—	—	—
Potential Gum ...	10 mgms./100 cc. max.*	10 mgms./100 cc. max.*	10 mgms./100 cc. max.*	10 mgms./100 cc. max.*	3 mgms./100 cc. max.*
Freezing Point ...	Below −60°C.	Below −60°C.	Below −60°C.	Below −60°C.	Below −60°C.
Maximum Lead Concentration	2.0 cc./U.S. gal.	3.0 cc./U.S. gal.	3.0 cc./U.S. gal.	3.0 cc./U.S. gal.	3.0 cc./U.S. gal.
Minimum Octane Number	73 & 80	87	73 & 80	87	80 & 87
Method	C.F.R. motor method	C.F.R. motor method	C.F.R. motor method	C.F.R. motor method	S.30 900/190
Acid Heat... ...	11°C. max.	11°C. max.	11°C. max.	11°C. max.	—

† In the U.S. Air Corps specification Y.3557/G. a special method of determining knock-rating is used.

The sample of fuel must be better than the Sub-standard reference fuel C.6 with the addition of 2 cc. T.E.L./U.S. gallon when tested in the C.F.R. engine modified in numerous ways. The most important modifications are:—

(1) The bore is reduced from 3¼in. to 2¼in.
(2) The engine speed is increased from 900 r.p.m. to 1,200 r.p.m.
(3) The degree of knock is measured by means of a temperature plug instead of the bouncing pin.
(4) The jacket temperature is increased from 100°C. to 165°C.
(5) No heat is applied to the mixture

As a matter of interest fuels meeting this specification generally have an octane number of about 87 when tested under motor method conditions

* By "Accelerated Ageing Test."

Appendix No. 6

Quantitative Evaluation of Aircraft Fuels.

Method suggested by Mr. E. L. Beall of the Wright Aeronautical Corporation.

Since the method employed by the C.F.R. Committee for the comparison of fuels is only qualitative, the following method has been suggested by Mr. Beall to obtain quantitative results.

The experimental data required is that given by a mixture control run as recommended by the C.F.R. Committee (see page 895 and Fig. 16). The determination is as follows:—

(1) Select by inspection of the plotted data the fuel which first reaches a critical head temperature. All comparisons are made at this fuel flow, which is usually the lowest at which it is possible to secure a reading.

(2) The head temperature, power output and specific fuel consumption are each taken from the curve at the fuel flow at which the poorer fuel reaches its critical head temperature.

(3) Using the data obtained by this means the following equation can be applied:—

$$\text{Fuel match No.} = 100/\text{specific output} + \text{maxm. head temp.} + (\text{fuel cons.} \times 10^3).$$

Specific output in b.h.p./cubic inch.
Head temperature in °F.
Fuel consumption in lbs./b.h.p. hour.

(4) As an example, the following data was obtained from two curves of 73 and 80 octane respectively. In this case the 73 octane fuel was the reference fuel and the 80 octane a benzol blend:—

C.F.R. octane No.	73	80
Maximum head temperature...	512°F.	467°F.
B.H.P.	521	537
Fuel consumption—Gross ...	322lbs./hr.	322lbs./hr.
Specific ...	0.617lbs./b.h.p. hr.	0.590lbs./b.h.p. hr.
Match number of fuel... ...	1430	1349

(5) The results obtained by this method have checked satisfactorily with those of the C.F.R. Committee. It is considered that a satisfactory match between fuels is obtained when the match numbers are within 15 points.

Appendix No. 7

Detonation and Cylinder Head Heat Losses.

It is generally assumed that detonation in gasoline engines is the sudden inflammation, due to self-ignition, of the so-called "end gas," *i.e.*, the last gas to be reached by the propagated flame.

As the speed of reaction of this inflammation is very high, extraordinarily high local pressures may occur. These pressures cause a strong blast of combustion gases to those places where the pressure is lower, and it seems probable that it is this rapid gas movement which contributes to the increase in heat loss which accompanies detonation. It is well known that heat losses in an engine are dependent *inter alia* on turbulence. For example, it is more difficult to start a turbulent Diesel engine than a quiescent one, due to the greater heat loss; also the heat to the cooling water generally increases with turbulence. Mr. Pye[36]

[36] See Reference No. 24, page 905.

has also pointed out that the " receptivity "[37] of the piston moves up roughly with the speed due to the differences of gas turbulence.

The gas movement, created by detonation, even if only local, is of the order of sound wave velocity, *i.e.*, 500 metres per second, whereas ordinary turbulence scarcely exceeds about 100 metres per second. The rate of heat transmission by convection in a detonating engine must therefore be very much higher than that in the most turbulent engine running without detonation. In addition, the rate of heat transmission will be increased in proportion to the high local pressures even if these do only occur for a very short time. The effects of these

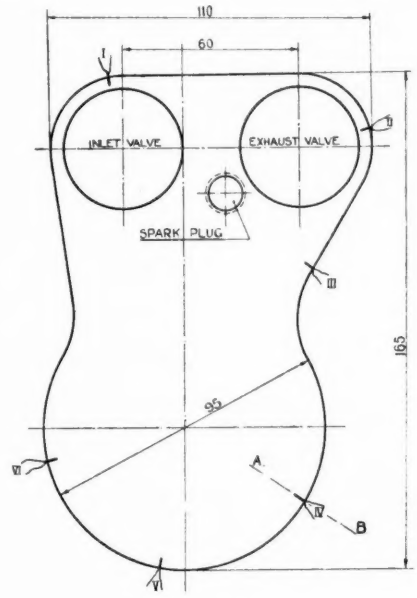


FIG. 1.

conditions will therefore be felt in the raising in temperature of the surfaces in the combustion chamber; the extent of the increase in temperature being greater where the gas velocity is higher. Also, the strong blast of extremely hot gases may reach the gas space behind the piston rings which will encourage the rapid carbonisation of the lubricating oil there. This effect will be in addition to that of the greater amount of heat which will be transmitted to the ring grooves on account of the higher temperature of the piston crown.

[37] " Receptivity " defined as the rate of reception of heat per square centimetre per degree centigrade difference of temperature between the piston and the gas.

Thus, some explanation may also be found for the variations in temperature rise which occur under detonating conditions at different parts of the combustion chamber. The following results have been obtained from experiments made in a side-valve water-cooled engine with thermo-couples embedded in the cylinder head gasket, as shown in Fig. 1 :—

Thermo-Couple Number	1	2	3	4	5	6
Position	Inlet Valve.	Exhaust Valve.	Edge of Cylinder (exhaust side).	Edge of Cylinder (remote from exhaust valve).	Between Nos. 4 and 6.	Edge of Cylinder (remote from inlet valve).
With detonation	247	363	205	242	170	205
Temperatures —°C.						
No ,,	247	364	200	225	164	187
Difference ...	0	−1	+5	+17	+6	+18

These observations clearly show the necessity for proper location of the thermo-couples if satisfactory indication of detonation is to be obtained; moreover, they indicate that a differential temperature measurement at suitable points of the engine may be used as a method of detecting detonation which has the advantage of being independent of the general temperature level.

Appendix No. 8

Piston Temperature Measurements.

Piston temperatures on a C.F.R. engine operating under motor method conditions have been measured by means of the apparatus illustrated in Fig. 1 and described below. Fig. 2 illustrates the rise in piston temperature with

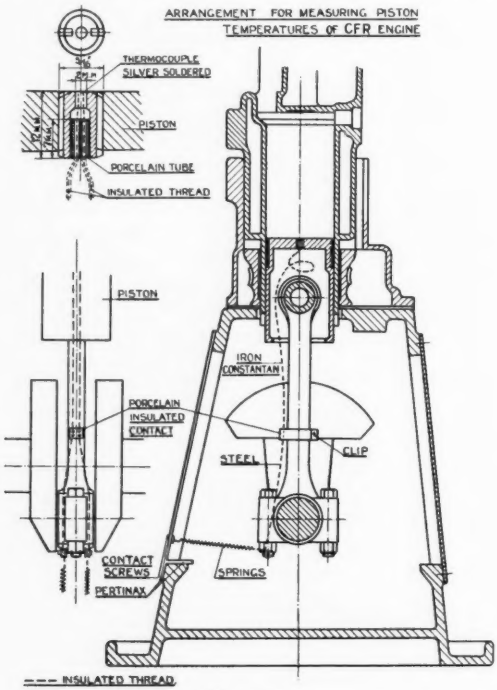


Fig. 1.

increased compression ratios and the onset of detonation; for purposes of comparison the temperature taken by means of a temperature plug inserted in the sparking plug hole, is also shown. The temperature plug used was similar to that shown in Fig. 18 with the exception that it projected only 10 mm. into the combustion space. In these tests, the sparking plug was inserted in the bouncing pin hole.

The conclusion to be drawn from these results is that the piston temperature appears to follow pretty closely the cylinder head temperature. It should be noted that owing to the peculiar design of the C.F.R. cylinder head and piston, the relative temperatures in a full-scale engine are almost certainly much more nearly equal than those indicated in Fig. 2.

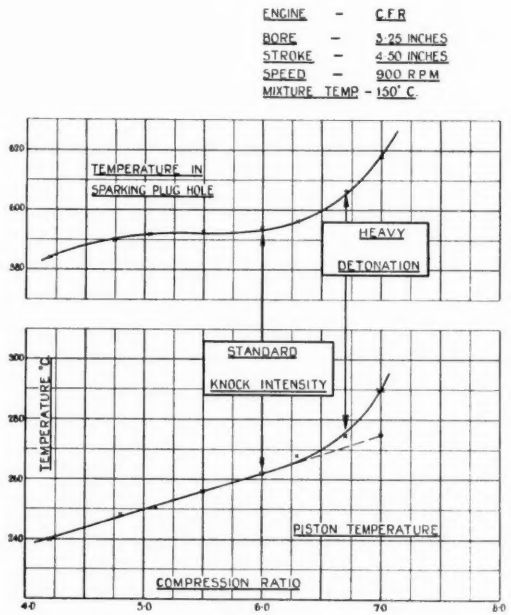


FIG. 2.

The method of recording the piston temperatures was as follows:—

An iron constantan thermo-couple was fixed in the centre of the piston crown, as shown in Fig. 1. As cold junction a porcelain connecter was fixed to the middle of the connecting rod, from which connecter the current was further conducted by steel wire. The cold junction was maintained at a given temperature by the oil; the temperatures measured are corrected for this. The steel wires were further conducted over two pulleys (fitted to a spindle which also serves as a split pin for the locking of the nut of the big end of the connecting rod).

The steel wires were insulated to beyond the pulleys, after which they were coiled and passed through two holes in the crank case lid made of insulating Pertinax. The spring-shaped parts of the steel wires were not insulated so that the springs should be able to follow the rapid movements of the connecting rod.

Discussion

Mr. D. R. Pye, F.R.Ae.S.: The Society must account itself fortunate in the fact that the large organisations concerned with the production and supply of fuels of all kinds were willing to allow their technical experts to give it the benefit of their experience. He recalled that about a year ago a very notable paper had been presented by Mr. Banks, of the Ethyl Corporation.

Referring to detonation, he said that Mr. Bass had quite rightly emphasised its great and steadily growing importance. Ever since 15 years ago, when Mr. Ricardo had first applied quantitative values to detonation, it had been in their minds; and Mr. Banks, in his paper to the Society a year ago, had shown how the brake mean pressure of an engine increased practically in proportion to the octane number of the fuel used in it. A great deal of research had been done on detonation, and they now understood a certain amount about the physical effects in a cylinder when it occurred. He did not find in the paper a picture which drew quite enough attention to what he believed to be the agreed sequence of phenomena. As Mr. Bass had rightly stated, detonation occurred normally by the exceedingly rapid combustion of what he had called the "end gas," *i.e.*, it might be quite local in the cylinder. Following that, there was a series of very rapidly travelling pressure waves across the combustion space; these were reflected back from the walls, then back again, and so on. In other words, detonation in the cylinder resulted in a vibratory condition in the compressed and extremely hot gas.

In Appendix No. 6 of the paper, Mr. Bass had referred to detonation as producing a very rapid air movement in the cylinder. But Mr. Pye did not think that that followed. He suggested that when detonation occurred in a combustion space a small part of the gas at the point farthest from the ignition plugs was burnt with exceeding rapidity, and gave a sort of "biff" to the rest of the contents of the cylinder. Just as, by striking with a hammer a long bar of iron, a pressure wave was created and ran along the bar, so in the cylinder pressure waves were created in the gas, travelling backwards and forwards, as the result of detonation; but he did not think there was a very great velocity of gas movement as a consequence. He believed that the increased heat loss resulting when detonation occurred was probably due more to an exceedingly rapid radiation loss than to increased loss by convection.

A further consequence of the vibratory nature of detonation was that it followed that the maximum pressure recorded was not the average pressure throughout the whole cylinder. Many of the spots shown on the record of the R.A.E. indicator represented just the flick of the pressure waves against the indicating disc. He believed that under detonating conditions there was not more than a slight general increase of pressure in the cylinder, and that the results given by Mr. Bass were not, therefore, contradictory of the conclusion quoted from Mucklow's paper, that "There is no evidence that the occurrence of even heavy detonation gives rise to any general increase in maximum pressure."

Coming to the rating of fuels, Mr. Pye discussed the efforts being made by the Air Ministry to keep up to date in the way of maintaining a satisfactory correlation between test engines and the full-scale engines in the new fields which were arising owing to the steady improvement of quality of the fuels available. As the author had said, about two years ago the Air Ministry had adopted the modified motor method, using the C.F.R. test engine. That was found to give very good correlation with fuels having an octane number up to about 75. At that time there were no fuels in service containing lead, and it was necessary to draw up a method of testing lead-containing fuels, which were about to be used, before there had been time to cover the ground in the research on correlation. Since that time the programme had been extended, and was being carried on along lines of comparing first the rating of fuels in the C.F.R.

test engine with the qualities of those fuels in single aero-engine cylinders, and now in complete engines. The Sub-Committee of the Institution of Petroleum Technologists which exercised a general supervision over this work was in the closest liaison with the American Committee organised by the Society of Automotive Engineers. The latter committee was carrying out a similar programme, employing American engines; and quite lately there had been a movement, which he hoped would be carried into effect, whereby similar experiments would be carried out in Canada, because clearly it would be to everyone's advantage to have on both sides of the Atlantic a common agreed method of testing fuels. That end was perhaps more especially desirable from the point of view of Canada. At the moment the programme in this country covered fuels having octane numbers up to 87, but it was not proposed to stop there. They would push on as soon as they were clear as to the lines of further progress for the improvement of octane numbers, so that in future he hoped they would arrive at a satisfactory test method for fuels up to the highest octane numbers likely to be available.

This led to the consideration of the methods the author had mentioned for detecting and gauging the presence and violence of detonation in full-scale engines —a very difficult problem. A matter of special interest in the paper was the author's reference to a number of lines of work in France, which perhaps had not been referred to before in the Proceedings of the Society. Mr. Pye recalled that two years ago he had met Monsieur Champsaur in Paris, and had discussed with him his method of detecting detonation by detecting an increase of heat in the cooling water. If the engine were suitable, that might be a very useful method; but the difficulty was that it depended very much on the design of the engine, and therefore, since one had to look for methods which applied generally, this method was not quite so satisfactory from that point of view. Some years ago Mr. Pye had asked Mr. Ricardo to attempt to detect detonation by this method on the E.35 engine—on which engine many of Mr. Bass' results were based—but Mr. Ricardo had failed completely; he was unable to find any rise of cooling water temperature when detonation was occurring. Perhaps the explanation was that the cooling water was in contact with the exhaust pipe beyond the exhaust valve. Mr. Pye suspected that there was more heat to the cooling water around the combustion space and rather less at the points beyond the exhaust valve. There was therefore a compensatory effect due to the particular design of the engine.

The results obtained by Mr. Bass in regard to exhaust gas temperature measurements were interesting, but apparently they all applied to the E.35 single-cylinder engine. In a multi-cylinder engine detonation might occur very badly, but it might occur in only one or two cylinders, and Mr. Pye suspected that the sensitivity of the method, if one tried to measure the average temperature of the exhaust gases from all the cylinders, might not be sufficient to render that method a useful one.

Mr. Pye suggested that one should be careful about interpreting the temperatures recorded in the paper in Fig. 20. In the first place, the author's thermo-couple for measuring the temperature of the exhaust gas was not measuring the temperature of the gas streaming out past the exhaust valve, but of gas at a far lower temperature. The temperature which damaged the exhaust valve was that which occurred when the valve just began to open, when the gas was at full pressure. Secondly, the thermo-couple was measuring the average of temperatures which were varying over a whole cycle, during half of which there was no exhaust gas flowing past it at all. Moreover, at full load the metal of the exhaust pipe would be hotter than at 70 per cent. load, and during the period of the cycle when there was no exhaust gas flowing the thermo-couple was subject to radiation from the hotter exhaust pipe surfaces. Therefore, the recorded temperatures under full and part throttle conditions would not bear

the same relationship to the true temperatures of the exhaust gas. It might well be that the gas temperatures which were important to the life of the valve might show a much smaller difference between full and part throttle conditions.

Mr. W. D. VAN OS (K.L.M.): During the past year it became more general practice to fly with commercial aeroplanes in use on the regular air lines at altitudes between 2,000-3,000 m. As a result of this it is a very important matter that the pilot regulates the mixture control of the carburettor as carefully as possible, because flying on an over-rich mixture means a waste of petrol, whereas flying on a too lean mixture can be responsible for serious harm to the engines.

With regard to this the K.L.M. has installed during the past year in most of their planes boost gauges and flow meters. The combination of the readings of the rev. counters, the boost gauges and altitude gauges gives an indication of the power developed by the engines, and from this they know what the most economical petrol consumption under these circumstances can be.

They have prepared diagrams, in which the pilot can find from these readings which is the required petrol consumption and with the aid of the mixture control he can adjust the carburettor following the reading on the flow meter.

They have got already very promising results with this system. To find out which was the most economical fuel consumption for all conditions of revs. and power, they had to carry out a lot of bench tests, and between those they have done similar tests with rich and weak mixtures, as described in Mr. Bass' paper. These tests have been done on the K.L.M. test bench installation at Waalhaven aerodrome.

To measure the cylinder temperatures they used a thermo-couple plug located in the starter valve hole of the master rod cylinder of a 420 h.p. Pratt and Whitney Wasp engine. The length of this plug, however, was short, so that the thermo-couple did not enter into the combustion chamber.

At various power loadings they found a drop in cylinder temperature by weakening the mixture—this in contradiction with the results given by Mr. Bass.

Is it possible that during the tests described in the paper detonations have been introduced by accumulation of heat in the part of the thermo-couple plug extending into the combustion chamber?

Mr. H. L. HALL (Imperial Airways, Ltd.): Mr. Bass had painted a picture of the future which was not very attractive to the aircraft operator, who had to try to make a living. It was indicated that the continued raising of the octane number of the fuel meant that the field from which fuel could be drawn would become smaller and smaller—and one supposed that that meant higher and higher prices. Mr. Hall hoped that the engine designers and fuel specialists would reduce the quantity of fuel required by the engines in proportion to the increase in the price of the fuel. However, he felt that if the very excellent research work which Mr. Bass had illustrated were continued, it would probably open up new lines of investigation, as the result of which the octane number might not play such a great part as it does at present.

In Mr. Hall's experience, evidence of detonation in civil aircraft engines was very rare. Illustrations were given in the paper of the effect of detonation on pistons; he had seen many pistons which had been damaged in that way, but changing the type of lubricating oil had put an end to the failures.

He was a little doubtful whether the improvement in respect of octane numbers was placing the petrol engine so much in front of the compression ignition engine as Mr. Bass appeared to have indicated. Therefore, he asked if Mr. Bass could give examples to show that the promises in respect of the high octane number fuels and the engines that were being developed to use them had materialised, or whether, as in everything else which man did, a compromise had had to be adopted because the goods were not quite " up to sample."

Another factor to be borne in mind was that those who were working on the compression ignition engine were working just as hard as are those concerned with developing fuels of high octane numbers for petrol engines. For long ranges—and they had yet to conquer the Atlantic by commercial flying—the compression ignition engine would play a great part, and he believed that the development of fuels of still higher octane numbers is not going to be quite so valuable to the practical man as some people believed.

M. E. PLOIX (Air France): Mr. Bass' remarkable lecture leads one to make two comments, one on the subject of detonation and the other on the freezing of carburettors.

(1) *Detonation.*

One could not stress too much the influence of detonation on aircraft engines, for the speaker believes that it is one of the principal causes of unsatisfactory engine running, failures of pistons, rings, valves, plugs, etc.

Conditions of Detonation.—If detonation occurs principally in aircraft engines at take-off or during climb when the engines are operating at full throttle and maximum torque—sometimes under conditions of unsatisfactory cooling—it can also occur under cruising conditions when the fuel is of too low an anti-knock value, or when some external condition has affected the carburettor setting or the general operating conditions of the engine. It can also occur under cruising conditions if an engine normally running on a fuel of sufficient anti-knock value is supplied at one refuelling point with a fuel of the same anti-knock value measured on the C.F.R. engine, but with which the commencement of detonation occurs at a different point compared with the original fuel.

Observed Facts.—Air France has observed this phenomenon on certain lines and it can mention two particular lines on which the same machines and the same engines have always been employed, and on which the operating conditions are to all intents and purposes equivalent, and where all conditions are the same except the fuel which, although of the same C.F.R. knock-rating, is not from the same source.

Causes of the Phenomenon.—After having investigated everything which could account for the difference in results obtained on the two routes, ignition, carburation, etc., it became evident that the only difference was in the country of origin of the fuel. The anti-knock values were exactly the same according to numerous checks made, first on the S.30 and then on the C.F.R. engine, but the composition was different. One of the fuels—that which gave rise to a considerable amount of trouble—had an aromatic content of between 4 and 8 per cent., whilst the other, which gave entire satisfaction, had an aromatic content of between 15 and 20 per cent. It was evident, therefore, that the composition of the fuels differed. The troubles encountered were of two sorts:—

(1) Certain occasional irregularities in the running of the engines apparently knocking; this phenomenon was referred to by the operating personnel as " le moteur accroche "—" the engine catches."

(2) The piston rings stuck more quickly; the valves and plugs occasionally appeared to be overheated. It was evident that it was a question of detonation.

Verification.—In order to arrive at a more exact interpretation of the causes of this, with the kind collaboration of M. Ninnes, of the Société Gnome et Rhone, they made some tests on a single-cylinder engine, using the cylinder, valves, etc., of the air-cooled K.7 engine, using seven different fuels. Although the facts observed in practice had occurred on a water-cooled engine and under less severe operating conditions than those on the single-cylinder air-cooled engine, the results showed the same trend.

TABLE I.

TESTS ON SINGLE-CYLINDER ENGINE—GNOME ET RHONE, "K" TYPE CYLINDER.

Number of fuels	1	2	3	4	5	6	7
Classification on "K" type single-cylinder							
Induction manifold pressure, mm. of Hg.	755 mm.	815 mm.	825 mm.	825 mm.	860 mm.	875 mm.	1000 mm.
Octane Numbers.							
S.30 150° 600	73.4	75.8	73.1	74.4	78.2	81.8	86.6
190° 900	69	70.2	68.8	68.6	70.2	75.7	77.2
C.F.R. 127° (modified motor method)	73.2	73.5	72.6	73.8	77	81	83
Specific gravity	0.732	0.763	0.745	—	0.769	0.745	0.818
Reid vapour pressure, kg./sq. cm.	0.278	0.278	0.286	0.336	0.314	0.327	0.265
Chemical Analysis.							
Olefines	0.68	0.15	0.17	Fuel	0.08	Fuel	0.21
Aromatics	4.48	33.08	19.26	No. 3	34.39	No. 3	69.20
Naphthenes	51.30	27.90	43.58	+ 10%	36.99	+ Ethyl	15.78
Paraffines	43.54	38.8	36.99	Benzol	28.54	—	14.81
Distillation.							
Initial boiling point	26	28.5	27.5	—	30.5	—	34
Twentieths: 1	65	66.5	64	—	66	—	74.5
2	70	71	68	—	71	—	79
3	73.5	73.5	71.5	—	74.5	—	81

	4	...	...	..	...	..	76.5	76	74	—	78	—	82.5
	5	...	...	...	...	...	79.5	79	76.5	—	81	—	83.5
	6	...	...	...	..	...	82	80.5	78.5	—	84	—	85
	7	...	...	...	...	...	84	82	81	—	87	—	86
	8	...	...	...	...	...	86	84.5	83	—	89.5	—	87
	9	...	...	...	...	...	88	86.5	86	—	92	—	88
	10	...	...	.	...	...	90	88	88.5	—	94.5	—	89.5
	11	...	...	...	...	...	92	90	90	—	97	—	91
	12	...	...	...	...	...	94	92	91.5	—	100	—	93
	13	...	...	...	..	...	96	94	93.5	—	103	—	95
	14	...	...	...	...	...	98.5	97	95.5	—	106.5	—	98
	15	...	...	...	. .	...	101	100.5	97.5	—	111	—	101
	16	...	...	...	...	. .	103.5	104.5	101.5	—	116.5	—	106
	17	...	...	..	...	...	106	109	104.5	—	123.5	—	115.5
	18	...	...	...	. .	...	109.5	115.5	108	—	133	—	125
	19	...	...	...	...	...	116	123.5	114	—	142	—	137
End point		...	...	...	...	...	137	138	132	—	158	—	153

NOTES:

Gasoline (1) Is unsatisfactory in practice.
,, (2) & (3) Are mediocre, giving rise to overheating of the cylinder head, and sooting, due to poor combustion.
,, (3) Excellent.
Gasoline (5) Excellent non-benzolised gasoline.
,, (6) Ethylised gasoline not employed in practice.
,, (7) Very heavily benzolised gasoline not employed in practice.

TABL

REPORT ON EXPERIMENTS WI HEAT

Test No.	Arrangement.	Speed in r.p.m.	TEMPERATURES. Oil inlet.	Oil outlet.	Atmos. (Engine Entrance).
1	2	3	4	5	7
A					
a	A.F. heating muffle No. 1, closed	1900	27	78	7[illegible]3.2
	Exhaust heat from one cylinder, without cap	2000	32	82	7[illegible]5
b	A.F. heating muffle No. 1, closed	1900	30	78	6[illegible]7
	Exhaust heat from one cylinder, with cap ...	1960	34	82	6[illegible]8.7
B					
a	A.F. heating muffle No. 1, closed	1900	32	78	6[illegible]4.3
	Exhaust heat from two cylinders, without cap	1960	34	83	6[illegible]5.5
b	A.F. heating muffle No. 1, closed	1900	32	78	5[illegible]4.7
	Exhaust heat from two cylinders, with cap ...	1940	32	81	5[illegible]8.9
C					
a	A.F. heating muffle No. 2	1900	34	80	8[illegible]4.5
	Exhaust heat from one cylinder, without cap	1980	35	84	8[illegible]4.8
b	A.F. heating muffle No. 2	1900	34	80	8[illegible]8
	Exhaust heat from one cylinder, with cap ...	1940	35	84	8[illegible]8
D					
a	A.F. heating muffle No. 2	1900	30	79	8[illegible]3
	Exhaust heat from two cylinders, without cap	2000	35	85	8[illegible]2
b	A.F. heating muffle No. 2	1900	35	82	6[illegible]7.3
	Exhaust heat from two cylinders, with cap ...	1910	40	86	6[illegible]5.8
E					
a	A.F. heating muffle No. 3	1900	29	77	5[illegible]2
	Exhaust heat from one cylinder, without cap	1960	32	81	5[illegible]1.3
b	A.F. heating muffle No. 3	1900	30	80	6[illegible]7
	Exhaust heat from one cylinder, with cap ...	1920	35	83	6[illegible]5.8
F					
a	A.F. heating muffle No. 3	1900	33	79	7[illegible]2.5
	Exhaust heat from two cylinders, without cap	1910	37	83	7[illegible]0.7
b	A.F. heating muffle No. 3	1900	36	82	8[illegible]3.2
	Exhaust heat from two cylinders, with cap ...	1900	41	85	8[illegible]3.2

TABL

TS WI EATED AIR INTAKES, ETC.

TEMPER	TRES.							
Atmos.	Engine Entrance.	Elbow.	Temp. rise due to the heating muffle.	Temp. drop due to evaporation of the gasoline.	Fuel consumption in litres/hr.	Pressure at bottom of heating muffle—mm. water.	Max. speed—r.p.m.	Observations.
7	7	8	9	10	11	12	13	14
7	3.2	+5.7	15.7	17.5	116	+150		
7	1.5	+5.9	14	15.6	141	+160	2000	Barometric pressure = 730 mm. of mercury.
0	7	+7.5	20.5	19.5	123	−10		
0	5.7	+9.1	19.2	16.6	137	−20	1960	
0	4.3	+9.2	17.8	15.1	116	+110		
0	3.5	+10	17	13.5	138	+120	1960	Barometric pressure = 729.5 mm. of mercury.
5	2.7	+9.9	27	22.8	123	+30		
5	8.9	+12	23.2	16.9	138	+30	1940	
8	4.5	+5.5	16.5	19	117	+100		
8	4.8	+6.5	16.8	18.3	138	+110	1980	Barometric pressure = 737.5 mm. of mercury.
8	8	+9.1	20	18.9	111	−110		
8	8	+9.7	20	18.3	123	−130	1940	
8	3	+13.5	24.5	19.5	114	+60		
8	2	+15	23.5	17	136	+70	2000	Barometric pressure = 737.5 mm. of mercury.
9	7.3	+16.1	27.8	21.2	119	−60		
9	5.8	+18.1	26.3	17.7	126	−70	1910	
3	2	+8.5	26.5	23.5	125	+80		
3	1.3	+9.5	25.8	21.8	142	+90	1960	Barometric pressure = 732 mm. of mercury.
0	7	+13.5	30.8	23.5	117	−120		
0	5.8	+15	28.4	20.8	127	−140	1920	
7	2.5	+14.2	35.5	28.3	128	+50		
7	1.7	+15.1	34.7	26.6	136	+60	1910	Barometric pressure = 730.5 mm. of mercury.
8	3.2	+22	35.2	21.2	126	−70		
8	3.2	+22.8	35.2	20.4	128.5	−80	1900	

Some Further Facts.—Some other facts observed in practice have confirmed their idea that the composition of the fuel has a large influence on the satisfactory operation of the engines. Thus, for an engine rated for a fuel of 80 octane number by the C.F.R. engine, it is preferable to employ a fuel containing no or very little benzol rather than a heavily benzolised fuel, and they have found that the addition of more than 30 per cent. of benzol to a fuel can give rise to overheating and occasionally sooting up. On this last point they are entirely in agreement with Mr. Bass (Fig. 16 of his lecture). On the other hand, if one can use for these engines a fuel without benzol but containing natural aromatics, the results are excellent. These two facts have been confirmed by tests on the " K " cylinder mentioned below.

Method of Operation for the Tests on the " K " Cylinder.—The single-cylinder engine was adjusted to give maximum power without audible detonation. The anti-knock value of a fuel was determined by the maximum induction pipe pressure which could be tolerated without detonation. The attached table gives the results of these tests and the relevant compositions of the fuels.

Conclusions.—From the above they have concluded that there is not always good correlation between the results obtained on the C.F.R. or the S.30 engines and those obtained with a full-scale engine. In their opinion this lack of correlation arises from the fact that on the C.F.R. and S.30 engines the comparisons are made at maximum detonation whereas in a full-scale engine one tries to have no detonation. It is certain that the composition of a fuel plays a part and according to the composition there is a variation in the difference between the beginning of detonation and maximum detonation. They propose, therefore, that in the future a method should be used which will allow of comparison of the fuels, not according to the C.F.R. method at maximum detonation, but on the contrary at the commencement of detonation. The test engine should be adjusted to maximum power, and the beginning of detonation could be determined by means of an instrument similar to the " Detonindex."

(2) *Freezing in the Carburettors.*

Observed Facts.—Air France aeroplanes are frequently flying under very severe operating conditions, snow, hail, rain, etc. They have made a very close study in flight of the question of freezing and they have come to the conclusion that there are four sorts of freezing :—

(1) Formation of ice in the venturi of the carburettor. This sort of ice formation generally occurs if the aircraft encounters snow or ice in such a way that a large quantity of snow or ice can enter the carburettor. The formation of ice in the venturi can lead to a complete choking of the air intake as they themselves have seen during January, 1935. This formation of ice occurs under well-defined atmospheric conditions, in general very bad conditions, and for this reason it is only rarely met with.

(2) Formation of ice on the throttle valve. This form of ice formation is much more frequent. It can lead, if allowed to persist, to formation of ice in the venturi as in the previous case. In general, rapid movement of the throttle control is sufficient to cause the ice to fly off.

(3) Formation of ice on the jet. This is the most frequent case. The ice forms an obstruction which alters the air flow round the jet and gives rise to variations in the fuel flow. Under these conditions variations in the engine speed have been observed, and sometimes even weakening of the mixture strength to such an extent as to damage the plugs. They have observed this form of ice in February during trial flights on a new machine, and it is the most frequent form of freezing of the carburettor.

(4) Formation of crystals in the fuel. This occurrence is extremely rare and it can only occur if the fuel has an extremely high benzol content and if

before flight it has remained in stock for a number of days under extremely cold conditions. Petrol is an extremely bad conductor of heat, and they believed that if the tanks are full of fuel at a temperature of 4°C. to 5°C. the aircraft can make very long flights without the temperature of the fuel dropping sufficiently to lead to the formation of crystals in the jet.

Methods of Prevention.—In order to remedy these different sorts of freezing, it is necessary to keep the walls of the venturi, the throttle valve and the jet and its support at a sufficiently high temperature to prevent the ice adhering to them. Finally, it is necessary to prevent the formation of particles of ice in the fuel/air mixture. Such particles can damage the blades of the fan or the supercharger. To obtain these results they believe it is absolutely necessary to heat both the body of the carburettor and the air intake.

(*a*) *Heating the Body of the Carburettor.*—This is generally accomplished by circulating hot oil, but certain manufacturers have produced carburettors in which the body is heated by exhaust gas. They prefer the first method (heating by oil) to the second.

The heating of the body of the carburettor should be sufficient on the one hand to provide enough flow of heat to prevent too great a drop in temperature on the walls of the carburettor during a long glide, and on the other hand, it should not be so great as to give rise to gassing of the fuel in the float chamber. Heating by exhaust gas is insufficient for slow running, and they have actually observed during glides, differences of more than 40°C. between the air intake temperature and the temperature of the fuel/air mixture. On the other hand, it is too great during normal flight, and they have been able to observe on an aircraft in certain cases, gassing of the fuel which had a marked deleterious influence on the running of the engine.

(*b*) *Heating of the Air Intake.*—Heating by oil is quite insufficient to prevent the first three forms of freezing mentioned above. As a result of numerous experiments made on the bench they have shown that the drop in temperature due to vaporisation of the fuel can vary between 15 and 35°C. according to carburettor setting, throttle opening, and the engine speed. They have checked up in flight that with heated carburettors and even with slightly heated air intake it is possible to experience these three forms of freezing. For this reason they have designed and fitted to their machines heated air intakes which raise the temperature of the air in the same proportions. In addition, a shield is arranged over the mouth of the air intake so that snow or ice or even rain encountered in flight cannot get into the carburettor. A number of tests have been made with this apparatus which showed both on the bench and in flight that with the Gnome et Rhone K.7 engine the heating had only a very small influence on the power output of the engine. On the other hand, the power output was considerably influenced by the shape of the air intake and by the presence and shape of the shield. Table II shows a few results obtained on the bench with different forms of air intake with and without the shield and with various forms of shield, and also heated by the exhaust from one or two cylinders. The maximum speeds recorded should be compared with the maximum generally obtained without the air intake, which is from 2,000 to 2,030 r.p.m. It is noticeable that the drop of maximum speed is not more than 30 r.p.m. with the type of air intake adopted.

Dr. von Philippovich: In judging aircraft engine fuels, the most important* preliminary condition is undoubtedly to obtain a suitable *testing process*, by means of which their behaviour in the *aircraft engine* itself can be gauged. Now this gauging has two great disadvantages: it is dear, and, owing to the difficulty of keeping at the same time to the conditions of the test, inaccurate. The nearest approach to reality appear to be *tests* made in an *aircraft engine single cylinder*, because in this it is possible to keep to exact test conditions. Differences, in

* Translated from German text.

the estimate of fuels, between aircraft engine multi-cylinders and single cylinders of the same kind are only likely to exist in that the multi-cylinder engine has less work to do than the single cylinder, when—other conditions being equal—the most essential point, viz., distribution of the mixture, is taken into consideration. It is well known that, by weakening the mixture, the combustion chamber temperatures rise considerably—in many cases up to 100°C. and more—so that the greatest danger consists, then, in a cylinder containing too weak a mixture. In the case of multi-cylinder engines, irregular distribution of the mixture takes place, and this changes considerably—quite apart from the volatility of the fuels—with the number of revolutions, in such a way that alternately with the various number of revolutions, a different cylinder receives the weakest or the richest mixture. The selection of a certain cylinder in the aircraft engine as a place for measuring is, therefore, not absolutely reliable. In the single-cylinder engine, the introduction of various mixture conditions for testing fuels is advisable, so that the whole mixture range is thoroughly tested from weak to rich. In this way, the conditions of the aircraft engine are imitated to a great extent, and one can be sure of having also tested at the most dangerous working conditions.

As a *measuring process*, an integrating process comes into consideration, which works fundamentally in the same manner as the bouncing pin, *i.e.*, it receives pressure or temperature momenta over a certain period, and allows the mean value to be read off. It should be carried out as quickly as possible, *i.e.*, the best thing would be to carry it out in the combustion chamber, without, however, influencing the combustion. (In this connection he would ask the lecturer whether investigations had been made with regard to these influences?) As hitherto there are no pressure gauges available of the kind suggested, it is necessary to use the temperature gauge, as explained by Mr. Bass; the combustion chamber mean temperature and exhaust gas temperature can be advantageously determined at the same time.

As a *testing process*, the gauging of temperature is advisable, in certain conditions adapted to practical working, the mixture conditions varying throughout from rich to weak. This kind of gauging will be mainly suitable when it is a matter of testing the fulfilment of the minimum requirements for working a certain engine; in order to approximate most nearly to the conditions of the aircraft engine, however, it is necessary to use in the single-cylinder engine a cylinder of the same type of construction as that in the aircraft engine. If, on the other hand, in general, an estimate of aircraft engine fuels is to be made, in fixed conditions and graded compressions (*e.g.*, 5 : 1, 6 : 1, 7 : 1), temperature curves will have to be taken with regard to mixture conditions. It is advisable to indicate mixture conditions not only in grammes/b.h.p./hour, but also in cal./kg., because in this way the thermal properties of fuels are more accurately estimated.

Lower combustion chamber mean temperatures and increasing exhaust gas temperatures with rising octane number in the liquid-cooled single-cylinder engine correspond, according to the measurements of D.V.L., to the curves shown by the lecturer in Fig. 25. If the fuels had been tested with regard to the whole mixture, the doubts expressed by the lecturer would not have existed, namely, as to whether aircraft engine fuels should actually be tested in conditions which would cause, in practice, unbearable knocking. Of course, the reply to the question as to what degree of knocking would be really endurable in aircraft engines, is of essential importance. It can only be answered by long-period tests carried out for this purpose with fuels of various anti-knock properties.

In conclusion, he would like to ask the lecturer what are his views with regard to the use in aircraft engines of cracking benzene or benzenes with a high content of unsaturated matter.

Miss SPICER: The only two troubles she had experienced were, first, in

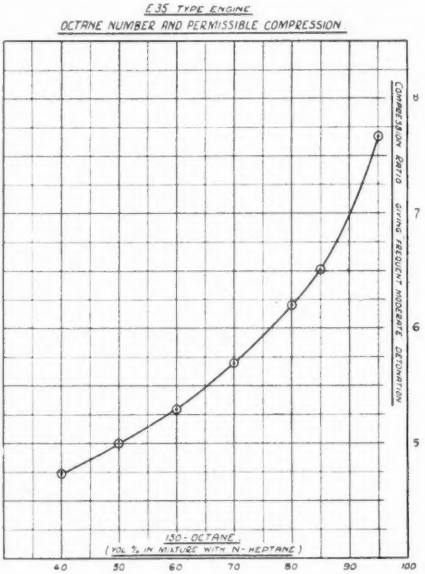
connection with startability—the 25 per cent. temperature was about 75°C.—and secondly, the formation of a gummy deposit in the jet.

Mr. O. THORNYCROFT (Ricardo and Co.): He subscribed to the view expressed by Mr. Hall concerning the importance of present developments in the compression ignition engine. However, it had to be admitted that the oil engine at present weighed about 1lb. per h.p. more than the petrol engine, where the latter had been designed for the high octane number fuels now available.

The use of iso-octane as a commercial fuel, the possibility of which had been referred to in the paper, was certainly a most interesting suggestion. The further freedom from detonation that such a fuel would provide would make such a development of as great importance as the introduction of lead ethyl was a short time ago.

He asked whether full-scale tests of aircraft engines had been made on commercial iso-octane and, if so, whether any unexpected trouble such as pre-ignition had been observed.

The E.35 type single-cylinder engine, referred to in the paper, had been run on pure iso-octane, and even at a compression ratio of nearly 8 (the highest possible for mechanical reasons in that engine), no detonation, and no pre-ignition, was observed. The curve relating to compression ratio and octane number (the volume percentage of iso-octane in a mixture with n. heptane) had been determined for this engine. The curve illustrated the very great potential improvement resulting from an increase of only a few octane numbers to a high octane fuel of, say, 90 octane number.



The author seemed unduly pessimistic about the possibility of evaluating the anti-knock properties of petrols in terms of their behaviour in full-scale aircraft engines. He had criticised the aural method which was used with aircraft single-cylinder engines in the tests carried out for the Institution of Petroleum Technologists. Mr. Thornycroft suggested that the results given in Fig. 24 of the paper did not support that objection. This showed that the aural

method of detecting detonation in the E.35 type engine gave almost perfect agreement with the method employing the drop in exhaust temperature, and, furthermore, both these methods gave fairly close agreement with that in which a " temperature plug " in the cylinder was used. The results, however, did show very clearly that two fuels that were matched in anti-knock rating in the C.F.R. engine, under " motor method " conditions, might be found to differ greatly when tested in the E.35 engine.

The Labarthe indicator, to which the author had referred, was a very interesting piece of apparatus. Diagrams taken with this instrument on a high speed engine in which detonation was evidently present showed very clearly the vibratory condition of the gas charge, the phenomenon which Mr. Pye had already described.

Ir. A. PH. MEYER (K.L.M.): Under the heading of " vapour pressure " Mr. Bass gives several prescriptions in order to avoid the occurrence of vapour locks in the fuel lines. In connection with this it should be interesting to observe that in K.L.M. (Royal Dutch Air Lines) practice two methods have been found suitable to reduce the vapour lock formation.

The first one consists in weakening the mixture strength at high altitudes, from which results a considerable reduction of petrol flow through the lines. K.L.M. has found that by reducing the consumption following the special diagrammatic prescriptions mentioned by Mr. van Os, the locks in the suction lines will mostly disappear.

The second method is a more negative one. To avoid vapour locks the fuel pump manufacturers increase the capacity of the fuel pump. This gives, however, a larger fuel circulation through the relief lines, which often are located in the neighbourhood of the engine, so that all petrol circulating through the lines is continually warmed up and the quantity of vapour will be increased. The effect will be the more serious as in general the circulating petrol is constantly irritated by an unsuitable installation. We, therefore, are of the opinion that in case vapour trouble happens with a certain installation, better results may be obtained by decreasing the pump capacity.

Mr. R. STANSFIELD (Anglo-Persian Oil Co., Ltd.): In addition to the several methods referred to by the author for determining the onset of detonation—he seemed to prefer a method which indicated the very beginning of detonation—there were two other methods, one of which had been developed and one which was being developed fairly widely. Professor Taylor, of the Massachusetts Institute of Technology, had devised an indicator which would fit into the space taken by an ordinary sparking plug, and therefore, unlike the optical indicator, could be used in an air-cooled engine without interfering with the cooling. The cylinder unit consisted of a fairly stiff diaphragm with moving coil attached; the coil vibrated, due to the pressure changes in the cylinder, at low frequencies, and also at high frequencies with the detonation shock, in the field of an electromagnet. Leads were taken to an amplifying circuit, which amplified the currents produced by the cylinder unit, and a high pass filter was arranged in the circuit so that the output of the indicating meter did not contain any record of the compression pressure or the normal rates of pressure rise during firing. These were filtered out, but the high frequency changes due to detonation were shown on the meter, and it was possible to detect, in such an engine as the C.F.R., and probably in others, a knock which was almost too light to be heard by the ear even in a quiet-running engine. The instrument was developed primarily for knock testing of fuels, but it might be useful in full-scale aero engines. It should not occupy more space on an engine than the " Detonindex."

The second line of progress was the development, in almost every country from which he had information—in Germany, France and Great Britain, and in at least two laboratories in America—of the use of electrical indicating units in the cylinder in conjunction with the cathode ray oscillograph. During the last

three months he had been experimenting with this type of equipment at the Sunbury Laboratory of the Anglo-Persian Oil Company; it provided a most amazing and flexible tool for engine work. Using a stiff diaphragm, having a natural frequency of the order of 25,000 or 30,000 per second, with a " speech " coil close to the diaphragm and surrounding a field magnet, pressure changes in the cylinder gave current changes in speech coil varying with the rate of pressure change. At the moment of detonation there was an extremely high rate of pressure change. He believed that particular method might be applied to full-scale aero engines without great difficulty, because the apparatus on the engine could be made of such small dimensions.

If a pressure diagram were required, it was quite simple to integrate the diagram of rate of change and to obtain a pressure-time card from the velocity-time card. The instrument was so sensitive that it was possible to spread one degree of crank angle, with an engine speed of, say, 2,000 r.p.m., to $\frac{1}{4}$-inch length of diagram or more.

There was one point regarding octane number determinations which was apt to be overlooked by those who grumbled about lack of correlation of laboratory results with full-scale work. If one aero engine were run on, say, four fuels, and those fuels were suitably doped or blended to make them all give the same results—the same incipient knock point, for example—it was usually possible to adjust any knock-testing engine to make those four fuels give results which agreed on that engine. There might be exceptional cases, but not many. But that was not the end of the correlation problem. If these same four matched fuels were run in other makes of full-scale aero engines at incipient detonation, the results obtained with the fuels might vary because of the differences in engine design by the equivalent of two or three octane numbers. The best that could be done with the C.F.R. was to make it agree with either an extreme or the average aero engine as might be required. The C.F.R. engine was a good instrument for knock testing, but the small differences between one engine and another and between one laboratory and another made it necessary to allow a range of, say, two octane numbers as an experimental and engine difference tolerance. Mr. Stansfield suggested that it was necessary to allow the same tolerance for the aero engines themselves. If a specification for a fuel were 87 octane, the engine builder should not design his engine to run just to the permissible detonation limit on that fuel; he must allow a tolerance of the same order as that which had to be allowed in the laboratory engine, and should design his engine to run on a fuel of, say, 85 octane, thereby making an attempt to cover the inevitable differences between one aero engine and another. These differences rendered it impossible to get complete correlation between laboratory results and those obtained in full-scale service, and ought to be allowed for by running type tests on fuels having a factor of safety of about two octane numbers below standard specification ratings.

Mr. F. R. Banks (Ethyl Export Corporation): It seemed, from the work done during the last few years and the information given in the paper, that there was fair agreement that temperature measurement was, so far, the most satisfactory method of ascertaining the effect of detonation and/or overheating in large aero engines; and temperature and its effects were, after all, the important considerations in large high duty engines. We were offered three positions for temperature measurement, (1) by means of a temperature plug inserted into the combustion chamber, (2) by thermo-couples embedded in the cylinder head and base, and (3) by a temperature plug of the thermo-couple type projecting into the exhaust system. From his own experience he rather favoured the use of the embedded thermo-couple in the cylinder head and the cylinder base, rather than the projecting types, because when these latter were stuck into the combustion space or exhaust pipe they acquired deposits, to which they were very sensitive, and the results obtained were apt to be exceedingly misleading. A great deal

had been done in America with regard to measuring exhaust temperatures, and similar troubles to those described by Mr. Bass as the result of his work on the E.35 had been experienced also. These were, that any air disturbance, such as draughts, around the exhaust system affected the results considerably, and particularly in the case of the American tests, with multi-cylinder radial engines, it was almost impossible to keep within the limits of reasonable accuracy. Mr. Bass had referred in the paper to a temperature plug projecting into the combustion chamber 30 mm., which had given very satisfactory results. But Mr. Banks feared that in the case of an aero engine one would never get away with such a fitment, because the plug would become a heat accumulator and cause overheating. Even if detonation did not occur, the results would be very doubtful. So far as pressure indicators were concerned, he did not think that such things as the " Detonindex " were of real use; the results obtained depended so very much upon their location in the cylinder; further, with the decreasing tendency to use gas starters, there were less holes in the cylinder and they were limited to the sparking plug positions, but one could not take out the sparking plugs and insert such instruments when seeking the detonation characteristics of fuels. He would welcome some means of measuring accurately the piston temperatures. This, if practicably possible, would help matters considerably.

In the section of the paper dealing with the effect of intake mixture temperature upon the anti-knock characteristics of a fuel, it was stated that the evidence available appeared to be conflicting, and the experiments of Ricardo on a sleeve valve engine had shown that an intake mixture temperature range of from 25°C./30°C. to 75°C./80°C. had no appreciable effect on the tendency to detonation up to boost pressures of 3.5 atm. (absolute). Mr. Banks said he believed the engine referred to was a very low compression engine and it was his experience that a low compression engine was far less sensitive to changes of intake mixture temperature than was a high compression engine. It also depended largely upon the fuel used and how near to its effective anti-knock value the engine was operated during the tests. In any case, there was ample evidence obtainable from the aero engine people that the mixture temperature influenced the effective anti-knock value of a fuel, particularly in the case of the high duty engine.

In general, Mr. Banks agreed with the statement in the paper that even under the most favourable conditions the tendency to detonation would diminish less under throttled conditions with the supercharged than with the normally aspirated engine; but he did not think one could possibly compare a supercharged engine with a high compression engine, because there was no basis for direct comparison. In one case it depended absolutely on the amount of boost with a given compression ratio and in the other, compression ratio only. How was one going to assess the equivalent of compression ratio only when dealing with the former combination? He admitted, however, that one must use quite different technique for the supercharged engine and the high compression non-supercharged engine. At a later stage in the paper Mr. Bass gives the difference in mixture strengths, for a given B.M.E.P., between single-cylinder and full-scale aero engines and quotes this as 15-20 per cent. He (Mr. Banks) thought that this was rather a wide range and considered that with modern engines it was more nearly 5-8 per cent. In this connection and in a later paragraph on the same page, Mr. Bass gives the results of some full-scale tests done at the R.A.E., Farnborough, using butane. These would seem to contradict to a certain extent his statements in the previous paragraph, although Mr. Banks agreed that the R.A.E. tests were not sufficiently conclusive without further work being done in this direction. Finally, with regard to the vexed question of obtaining correlation between laboratory knock testing results and the performance of full-scale engines, it would seem that the degree of correlation will have to be even more strict in future because high duty engines, as their

specific power outputs are increased, become more sensitive as regards fuel requirements and the equivalent of one octane number difference (which is, at the moment, within the experimental error between *laboratory* fuel testing engines) may be critical in the full-scale engine. In order to be on the safe side it might be a good idea, as suggested by a speaker at this meeting, to develop engines on fuels having slightly lower anti-knock values than those which would be supplied to the engines in service because it is inevitable that whatever fuel is specified for the engine manufacturer's use, the latter will always develop his engine to the practical limit of its capabilities, and those of the fuel.

Mr. W. W. WHITE: The work in the United States had reached a point at which the members of the C.F.R. Aviation Sub-Committee were venturing opinions as to the value of the C.F.R. octane rating method, and he offered those opinions for what they were worth. Apparently all were agreed that for straight-run fuels, the results of varying the octane numbers by means of lead, in the full-scale engines and in the C.F.R. motor, correlated very well indeed. The engines were two very high duty radial engines, one high duty Prestone-cooled engine, one medium h.p. air-cooled engine, normally aspirated. The results with all five had agreed, within the limits of experimental error, with the determination of the octane number in the laboratory, which was quite a favourable comment on the choice of test method finally adopted. For fuels blended with benzol the correlation was also quite good, with the exception that the C.F.R. motor method seemed to over-rate the fuels uniformly in practically all the engines by about $3\frac{1}{2}$ octane numbers; in other words, a fuel rated at $83\frac{1}{2}$ by the C.F.R. motor method was worth only 80 in the test on the full-scale engine. A similar effect with the C.F.R. motor method seemed to be indicated when dealing with fuels made by cracking, whether or not they were blended with lead. The C.F.R. tests did not include benzol blends with cracked fuels; the octane numbers of the cracked fuel were brought as high as possible by the addition of tetraethyl lead. In this case also the agreement seemed to be quite satisfactory as between the various engines, but the tendency of the C.F.R. motor was to over-rate the fuel uniformly.

A third series of fuels comprised aviation natural gasolines, very closely cut and containing a large percentage of stabilised casing head gasoline, but there seemed, at present, to be more difficulty in correlating with the C.F.R. motor method. In these tests there was apparently very good agreement up to the high octane numbers, but from 83 to 87 and 89 there was a gradual divergence. He did not know what means the committee was going to suggest to take care of that particular difficulty. Perhaps, when the tests on this group of fuels were complete, and proper opportunity given the Steering Committee to evaluate them, the solution would be simple. Obviously, it would be very easy to apply chemical tests to determine the percentage of benzol in a blended fuel or to determine whether or not a fuel was cracked and had any appreciable percentage of unsaturates. If the chemical tests indicated the presence of either benzol or cracked stock, an arbitrary correction factor could be applied, and that might be the best way to correct for these discrepancies. Mr. Stansfield had pointed out that the laboratory engine was quite flexible, and that the laboratory man could juggle his engine to a point at which it would rate the fuels satisfactorily; and that was the fundamental reason for the series of C.F.R. tests just being completed. It was recognised by the majority of engine manufacturers that if they were able to tell the laboratory people what fuel an engine wanted, a test to fit the conditions could be adopted; and it was only to be hoped that the Steering Committee and the C.F.R. Committee had time and energy enough to apply the things which the engine people had undoubtedly given them during this series of tests.

Mr. JEAN PONTREMOLI (*Fellow*, Gnome et Rhone): The various and complex problems involved for obtaining the best fuel for normal aircraft engines working

with a carburettor have been rarely, to his knowledge, explained in a better way. The difficulties are mainly because some of the fundamental characteristics have only recently been known, but the complete problem of combustion, still partly obscure, becomes every day clearer.

Mr. Bass has shown very clearly the thermic difficulties arising from detonation and their effect on destruction of pistons, first by ring sticking, then by more or less complete burning and disintegration of the crown of the piston. It might be interesting to note here that the destruction of the piston begins at a strictly localised part by pitting on the top, and that the part of the explosion chamber where this occurs corresponds exactly to that, where, in detonating running, the highest temperatures are reached. It is so possible to localise accurately the positions of a portion of the mixture charge which, instead of burning in a normal way, detonates. (This has clearly been shown by Mr. Serruys in his communication to the " Académie des Sciences," on the 27th of December, 1932.)

Later, Mr. Bass said that when taking pressure diagrams the positions of the indicator in the combustion chamber is not unimportant. He quite agreed with this opinion and they might be interested to know that some simultaneous diagrams have been taken from two different points of the head (near and far from the detonation centre) with the Serruys optical manograph of very high sensitivity. Definite differences have been registered between the two diagrams which enabled him to measure the speed of propagation of the pressure wave, which has been found to be around five hundred metres per second.

Mr. Bass mentioned that specialists are still hesitating to decide if light detonations can be allowed on aircraft engines or must be completely prohibited. The speaker is of the opinion that it is better not allowed. It may perhaps be possible that in the future a way will be found to utilise logically this special energy and that, contrary to present tendences, the most detonating engine shall be the best.

Mr. Bass is also worried by the fact that on engines specially built to study and classify fuels, it is very difficult to get close enough to the real conditions of aircraft engines in flight. Mr. Bass outlined also the anomalies of the modified motor method being less severe than the original motor method. It is possible that these lighter specifications are not due to pure technical reasons but to others, so as to leave a possibility for using benzol. It seems to him better to stick to the strictest conditions and to try to have the same all over the world. He would like to suggest an idea that he had had in mind for many years. He thought that the realisation of this idea could cause interesting improvements not only on fuels but also on engines. The progress of aviation has resulted in the development of large military or commercial planes, fitted with three, four, six, and more engines, flying at high speeds and climbing quickly to high altitude. Why, when several of those planes are ordered, not build one more which would be fitted as a complete flying laboratory? All engines except one to be standard engines, well known and well tested, the last one, connected to all laboratory apparatus, should allow them to make, under all flying and meteorological conditions, accurate comparative measurements. It would also become possible, on the engine itself, to carry out every desirable test and investigation. His short experience showed him that this would be a good positive and sure method. Another advantage would result in the possibility of testing a completely new engine in flight under the severest conditions, approximating to the intended use of the engine, without danger.

Finally, he would like to congratulate all the scientists for the work done in the last five or six years on fuel for aircraft engines. Improvements in fuels are responsible for the greatest increase in output and reliability of engines since then; and, by the way, development in flight altogether. He wondered if improvements in fuel characteristics can possibly continue at such an accelerated

rate. Even with the actual fuels, he thought that engine characteristics might be very much improved in the near future by taking into consideration the more accurate knowledge of the exact process of combustion which they were daily acquiring. They would probably find in the future much better designs of combustion chambers enabling them to get the efficiency and the pressure diagrams much nearer to the theoretical ones. This will only be possible by close collaboration between laboratories studying the properties of combustion and engine designers.

Mr. W. C. CLOTHIER (Royal Aircraft Establishment) (*contributed*): The term dew point appears to be used in some special sense in the paper for, if it is defined as the temperature at which initial condensation occurs, or at which the last drop of liquid evaporates it will depend on the air-fuel ratio and the atmospheric pressure. In the "S.A.E. Journal," November, 1928, p. 487, an alignment chart is given from which the dew point for air-fuel mixture may be estimated. For an aviation fuel similar to that of Fig. 27, the dew point of a 12:1 mixture will be 18°C. at ground pressures and it should therefore be possible to vaporise the whole of the fuel without exceeding this temperature provided efficient mixing and heating of the air fuel mixture is arranged.

With reference to the correlation between the A.S.T.M. distillation and the ice forming tendency, the tests made with the R.A.E. spray apparatus are not directly comparable with the American tests. The former apparatus measures the lowest temperature attainable with water free air, whereas the American measurements were limited to a definite mixture ratio and as far as can be determined from the published data the humidity of the air was not allowed for. The influence of humidity is very marked, see R. and M. 1549. The R.A.E. spray apparatus gives results which repeat very closely and allow a more accurate comparison to be made than do the American tests which are scattered very badly. This scattering may be explained by variation of the mixture strength reaching the thermometer bulb and by change of humidity.

The conclusions No. 2 from the American report on carburettor freezing requires qualifying, for in the body of their report ("S.A.E. Journal," p. 421, November, 1934) they state that for the mixture ratios within the service range there is reasonable agreement between the calculated temperature drops and that observed *if the heat absorbed by condensation and freezing of the moisture is neglected*. If ice is forming in any quantity this heat will not be negligible.

A thermometer exposed to the mixture stream in the induction pipe is not a good ice detector, for although ice cannot form when the temperature is above 0°C., a temperature below 0°C. does not mean that ice will form, in fact, unless a good deal of intake heat is used the temperature will generally be below 0°C. at altitude. This means that unnecessary intake heat will be used most of the time. To obtain a satisfactory indication of ice accretion it is necessary that the indicator should be influenced in some way by the formation of the ice.

Mr. H. CONSTANT, A.F.R.Ae.S. (*contributed*): The lecturer has referred to tests carried out to determine the conditions under which the C.F.R. engine would give the best octane number correlation with the rating obtained in aero engine cylinders. In these tests it was necessary for the C.F.R. intake temperature to be very much higher than that obtaining in an aero engine, in order to get good agreement. It seemed to him, therefore, that the agreement obtained was not fundamental but due simply to the cancelling out of opposing effects. The conditions under which the C.F.R. engine is run are so artificial and so totally different from those obtaining in an aero engine that there cannot be any real correlation possible between the two.

At the present time the two principal methods used for indicating detonation are dependent on the noise of the detonation and on its effect in bouncing a pin off the cylinder head. They are, however, not really interested in how high a pin will bounce or in how noisy the detonation is. Their principal interest in

detonation lies in the answer to the question: " What damage is it going to do to the engine?" Or in other words: " What overheating is it going to cause?" The effect of detonation on the piston and cylinder temperatures appears, then, to constitute their chief interest in this problem. Surely, then, it is logical to use cylinder temperature as a criterion of the degree of detonation or of the anti-knock value of a fuel.

If they use cylinder temperature as their criterion they are immediately faced with the danger of their results being masked by changes in temperature caused by alterations in the mixture strength. This difficulty may be overcome by measuring the variation of cylinder temperature during the execution of a consumption loop curve. If this loop curve be repeated for different fuels, including a non-detonating fuel, then the rise in cylinder temperature above that given by the non-detonating fuel at the same mixture strength would provide a measure of the unsuitability of the fuel. It would be necessary to repeat the test at increasing torques until the conditions were sufficiently severe to give a reasonable temperature rise.

He found the lecturer slightly misleading in his references to cylinder head temperatures. The temperatures recorded in Figs. 19, 20 and 25 must be some kind of average of the flame and head temperatures, the actual head temperatures being very much lower than the values he has given (ranging from about 500°C. to 750°C.). It is therefore not surprising that the temperatures he has recorded have their maximum values at a mixture strength about 110 per cent. of correct (corresponding roughly to the maximum flame temperature) compared with the true cylinder head temperatures (Fig. 21) which usually attain their maximum values at mixture strengths between 90 and 100 per cent. of the correct mixture.

He would be grateful for some more information about the formula proposed by Mr. Beall. Is it entirely empirical or upon what rational basis has it been constructed?

Major G. P. BULMAN, *Fellow (contributed)*: Opportunity having failed to present itself during the verbal discussion, a written communication must suffice to deal with certain statements which fell from one of the speakers.

The very happy freedom he recorded from the effects of detonation in the operation of engines under his direction was less an argument to discount the constant preoccupation of aero engine designers in problems of detonation, than an unsuspected compliment to those designers and those responsible for the rating and approval of British aero engines, and the airscrews allied with them, for civil use; such rating and the approved conditions of operation being especially defined to discourage to the utmost the onslaught of detonation in normal use. Whether or not the particular example shown by Mr. Bass in his illustrations is typical of detonation effect, there is not lacking the most convincing evidence in the scrap-heap adjacent to any progressive aero engine shop of what detonation can do.

In questioning how far the increase in octane value of the fuel would in reality produce the increased aero engine efficiency heralded by those who advocate further fuel development, the speaker appeared to the present author most unwarrantably to disparage the achievements not merely of the fuel suppliers in their scientific research and development, but also the aero engine constructors. It may be stated without equivocation that British aero engine constructors have responded magnificently, and to the fullest extent, to the opportunity given them by the introduction of the higher octane value fuel produced by the suppliers and covered by Air Ministry specification. Not merely has the power output been increased to the expected degree, but overload tests of more drastic character than ever before attempted have been completed with signal success.

There is abundant evidence, too, that in other countries the advantages of higher qualities of fuel, in providing the cheapest means of improving overall

aeroplane performance no less for civil than for military purposes, have been clearly realised and implemented. Care must, of course, be taken, when admitting the use of a superior fuel, to ensure that such fuel is available in such quantity and distribution as to ensure its economical employment.

Suffice it to observe that of the two standard British specifications (D.T.D. 224 and D.T.D. 230) of 77 and 87 octane value respectively, the latter, within the present author's experience, offers wider sources of supply, with no increase in cost per gallon, the while the consumption per horse-power secured is materially less.

Finally, expected mention was made of the advantages of the compression ignition engine in the usual sense that it is only the disinclination of the aero engine designers and those associated with them in their development programmes that is holding back the introduction of the heavy oil engine from wide use. Such reflection, again, most unwarrantably disparages the many years of strenuous effort and heavy expenditure put in to C.I. engine development in this country.

One would ask those (and there are many) who give lip service to the C.I. engine to address themselves to the following very practical and specific question:—

> Given the free choice of two engines of identical overall dimensions, form and weight, each to be cruised at 500 h.p.—one a petrol engine producing 820 h.p. for take-off with a cruising consumption of under 0.49lbs. per h.p., and the other a compression ignition engine giving 620 h.p. for take-off with a cruising consumption of 0.39lbs. per h.p., which will he choose, and for what kind of service?

An authoritative answer such as that speaker is well placed to give, carrying conviction that the provision of the C.I. engine outlined above would find an effective market of such a degree as to warrant the expenditure of time, money and energy needed to produce that engine (and it could be available in less time than it takes to establish a large civil prototype aeroplane), would go far to bring C.I. engine operation into practical reliability.

Reply to Discussion

In reply to Mr. Pye, to those particularly interested in the phenomenon of detonation in engines it is abundantly clear that no one theory can be made to fit the many different observations made from time to time. The cycle of events preceding and following detonation is so complicated that it is beyond human skill at present to obtain sufficient evidence at one time to enable a complete analysis to be made. For this reason the effect of the increased turbulence during detonation was only referred to in Appendix 6 as "likely to contribute to the increase in heat loss which accompanies detonation." This view is also held by Rassweiler and Lloyd Withrow[38] as a result of their own experiments and those conducted at the N.A.C.A.[39] In a paper by the former research workers it is stated that:

> "First, emission spectra have shown that the continuous radiation at the red end of the spectrum is stronger under knocking than under non-knocking conditions; that is, there appears to be more black-body radiation in the former case. However, on the basis of quantitative measurements, Marvin, Caldwell and Steele have recently concluded that there is very little black-body radiation from either knocking or non-knocking combustion. Second, flame pictures show appreciable

[38] Flame Temperature Variations, by G. M. Rassweiler and Lloyd Withrow. S.A.E. Journal, April, 1935.

[39] Infra-red Radiation from Explosions in a Spark-Ignition Engine, by C. F. Marvin, Jr., F. R. Caldwell and S. Steele. N.A.C.A. Report No. 486.

mass movements of the gases as the pressure waves set up by knock pass back and forth through the combustion space. The increased degree of turbulence resulting from this cause undoubtedly augments the rate of heat transfer to the walls."

With regard to Mr. Pye's remarks concerning the use of exhaust gas temperature measurements for the detection of detonation, it was not intended in the paper to infer that this method could be used for multi-cylinder engines—and certainly not with a thermo-couple in the manifold outlet. Obviously, the interference by exhaust gases from all but the one or two cylinders which may be detonating would be sufficient to mask any variations in temperature which occurred in the exhaust gases from the detonating cylinders. Further, the use of the exhaust gas temperature method does not appear attractive for multi-cylinder engines since variations in distribution and load will produce greater changes in temperature than detonation. Therefore, the method may be regarded at present as suitable only for single-cylinder engines for which there has been some demand for a means of detecting the early stages of detonation.

The limitations of the temperature measurements made on the E.35 engine were fully realised, and have been pointed out in the paper. With regard to Fig. 20, however, it is felt that in the absence of any evidence to the contrary the temperatures recorded gave a fairly reliable indication of the temperatures to which the exhaust valve was subjected. This view was taken as a result of the interesting correlation between the exhaust gas and cylinder head temperatures measured on the E.35, and the cylinder head and exhaust valve temperatures measured by Professor Gibson as mentioned in the paper. Taking this view, it still seems that the nature of the exhaust gases must play an important part in determining the length of valve life, in addition to the effect of temperature.

In reply to Mr. W. D. van Os, he thought that it was more likely the drop in temperature recorded by the thermo-couple in the cylinder head was due to the fact that that particular cylinder was already working at approximately the correct mixture strength, and it will be seen from the curves in Figs. 20 and 21, that on weakening down from this point a drop in cylinder head temperature is to be expected.

In the case of the experiments on the E.35 engine, the results of which are shown in Fig. 15, referred to by Mr. van Os, these were carried out with the engine first of all running excessively rich, and even when the change was made from rich to weak mixture strength, the mixture was still considerably richer than correct, and under these circumstances an increase in temperature would be expected, according to Fig. 20.

Had the change in temperature on the " Wasp " engines been due to detonation, it would be expected that the temperature would increase rather than decrease with the thermo-couple located in the starter valve hole.

Replying to Mr. Thornycroft, as far as he knew the only full-scale experiments with high anti-knock fuels of the order of 100 octane number were those conducted by the U.S. Army Air Corps and described by Lieut. Klein in a paper read before the Institute of the Aeronautical Sciences.[40] Also, of course, the engines of the " Macon " used such fuel, but no records of the results obtained appear to be available. None of the fuels used in Lieut. Klein's experiments contained more than 50 per cent. of iso-octane and no record of any troubles by pre-ignition were recorded in his paper. It was shown, however, that on standard engines not specifically designed for 100 octane fuel it gave an increase in power output of from 15 to 30 per cent., with, in some cases, lower cylinder temperatures than the standard 92 octane U.S. Army specification fuel.

[40] Aircraft Engine Performance with 100 Octane Fuel, by F. D. Klein. Journal of the Aeronautical Sciences, March, 1935.

It should be noticed in this connection that these octane numbers were determined by the U.S. Army method (see Appendix 5) and the equivalent octane numbers for these fuels by the C.F.R. motor method would be about 95 and 87 respectively.

The curve submitted by Mr. Thornycroft was of considerable interest and demonstrated clearly the fact that the practical value of each octane number in the high range (*i.e.*, of the order of 90) was far greater than that in the lower octane number fuels. This has also been shown in experiments carried out on a Lycoming[41] engine in America.

The author agreed with Mr. Thornycroft that Fig. 24 showed the E.35 engine to give results by the aural method very close to those obtained by the exhaust gas temperature measurements. Nevertheless, the results did show that from the point of " no detonation " to " frequent slight detonation " or to " frequent moderate detonation " one fuel required a greater increase in compression ratio than the other. Therefore, if these fuels behaved similarly in an aircraft engine and were rated aurally, one would give a greater factor of safety than the other if it were agreed that the danger point was that at which incipient detonation occurred. In any case the results given in Fig. 24 were more striking in showing the wide difference obtained on two fuels of equal anti-knock value as determined by the C.F.R. engine when tested at moderate or slight detonation either aurally or by exhaust gas temperature measurement in the E.35 engine.

Replying to Mr. Meyer, whilst the reduction in fuel flow effected by weakening the mixture strength at high altitudes may result in a perfectly steady flow of fuel to the engine, he did not agree that this procedure necessarily removed the vapour locks from the suction lines. To cause a complete blockage in fuel line, vapour lock had to be very considerable and occur very quickly, which as a rule was unusual in an aircraft fuel system in flight. Before the complete blockage occurred the effect of the vapour lock was generally to restrict the flow capacity of the fuel line, and if under the conditions mentioned by Mr. Meyer the engine were opened up to full throttle or the mixture strength enriched so that an increased rate of flow would be required, it is most likely that the vapour lock would be found still to be present.

With regard to the removal of vapour locks by altering the capacity of the fuel pump, as Mr. Meyer points out, this is likely to introduce a vicious circle. It is most necessary that if pumps of large capacity are used the fuel flowing from the relief valve should not be subjected to excessive heating. This generally involved the heat installation and/or cooling of the fuel pump itself, since as a rule more heat was picked up by the fuel pump than from other parts of the installation. Generally speaking, it was to be recommended that pumps of the minimum capacity consistent with the necessary factor of safety should be used, but they should be of such a design that they would be capable of maintaining their suction, even when they pulled gas only from the suction line if and when it formed in appreciable quantities.

In reply to Mr. Hall, he regretted he appeared to have given the impression that the picture of the future was not very attractive to the aircraft operator; this was quite contrary to the intention.

In Appendix 1 an attempt had been made to show the economic value of fuels of the future, providing the very best use was made of them, and these seemed to the author to indicate that they would have very appreciable economic value to the air line operator.

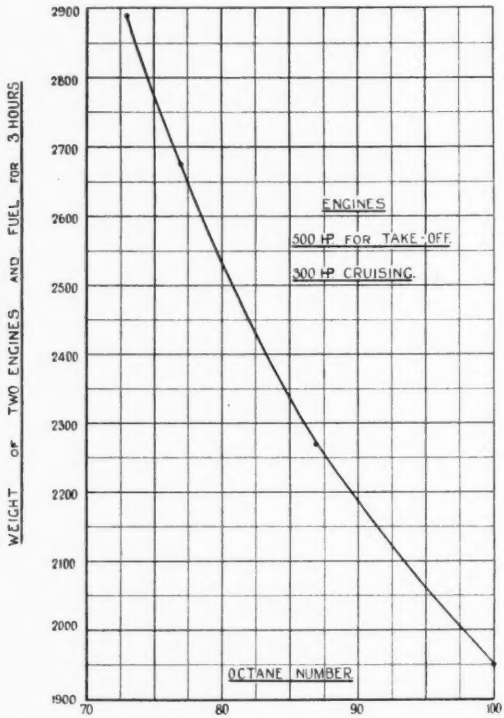
It was also felt that development in the past had shown the improvement in anti-knock value of fuels to be worth while, as evidenced by the following figures, which were obtained for well-known air-cooled engines of British manufacture :—

[41] Journal of the Aeronautical Sciences, May, 1935.

Fuel Specification.	Octane No.*	Engine Output B.H.P./litre.	Engine Weight lbs./B.H.P.	Fuel Consumption lbs./B.H.P./hr.
D.T.D. 134 ...	73	20.5	1.76	0.55
D.T.D. 224 ...	77	22.7	1.58	0.53
D.T.D. 230 ...	87	28.0	1.29	0.49
— ...	100	35.0	1.05	0.45

* C.F.R. modified motor method.

These figures have been used to construct the curve in the following figure, which shows clearly the value of increased anti-knock value of the fuel in improving pay load.



In actual fact, if these figures were utilised in Appendix 1 the economic value of the higher anti-knock value fuels would be found to be even greater than that shown. From this point of view, therefore, it seems that the promises in respect of engines using high octane number fuels had already materialised without the necessity for any compromise whatsoever.

With regard to the effects of detonation, illustrated in Fig. 2, page 881, the author assured Mr. Hall that no change of lubricating oil could possibly have influenced the final result in this case. Admittedly practically similar results can be obtained by using unsuitable oils, but in this case ring-sticking occurs first of all through an inherent property of the oil itself. True, the subsequent over-heating can induce detonation, so that ultimately the piston resembles one in which the original trouble was one of detonation.

The author agreed that the compression ignition engine was by no means dead, but there was no denying the fact that the introduction of high octane number fuels had given it a temporary setback. However, far more difficult

problems had been solved in the past by aero engine designers than those involved in the reduction of specific weight and the improvement of over load capacity for take-off, which were the chief obstacles in the way of the success of the compression ignition engine.

Although it was not apparent from the nature of the paper for the reason given in the introduction, the author, who had been associated with the early development of the high speed oil engine, subscribed to the hope that the development of the compression ignition aircraft engine should be accelerated so that its many advantages could be utilised to the full in civil aviation.

The information kindly given by M. Ploix was of the greatest interest. The fact that the C.F.R. knock ratings were so misleading with the two fuels compared was nevertheless disquieting, since one of the major requirements of the fuel testing engine is that it should determine the anti-knock value of the fuel without the necessity for any correction or adjustment arising from some other laboratory test. It was hoped that, as a result of the correlation work which had already been carried out, the C.F.R. engine was likely to meet this requirement, but the practical evidence supplied by M. Ploix clearly showed that in certain circumstances C.F.R. engine test results could be dangerously misleading.

One particular point of interest was the fact that the troubles recorded occurred on a water-cooled engine and the results obtained afterwards confirmed by tests on an air-cooled engine. Frequently the results obtained on these two types of engine were at variance, particularly when it came to comparisons between fuels of varying aromatic contents. For this reason it would seem that the air-cooled engine used for the tests was extremely well cooled and had a combustion chamber practically free from any hot spots.

With regard to the comparative value of added and natural aromatics, the experiences of M. Ploix confirm the practical and experimental evidence collected by the author. Benzene, toluene and zylene constitute the chief aromatics occurring naturally in gasoline and these are known to have appreciably higher effective anti-knock values than the normal motor benzol used in aviation fuel blends.

On the subject of air intake heating for the prevention of freezing, although M. Ploix had demonstrated that this method when used in conjunction with carburettor heating had been successful on typical engines of to-day, the author suggested that with the high supercharged engines likely to appear in the future it may be an added disadvantage to pre-heat the air for the reason that much of the cooling of the supercharger, due to the latent heat of the fuel, would be sacrificed. This may be of particular significance when the two-stage supercharger became common. For this reason the prevention of freezing by the use of alcohol on the lines suggested by Mr. Clothier,[42] of the Royal Aircraft Establishment, was particularly interesting.

Referring to Dr. von Philippovitch's remarks, the author agreed that in view of the difficulty in obtaining perfect distribution in a full-scale engine, it is desirable for the anti-knock value of fuels to be determined under weak mixture strength conditions. However, it would be difficult to suggest what mixture strength should actually be used, since the really weak mixtures were only employed as a rule under cruising conditions when the tendency to detonation was reduced by virtue of the reduced output of the engine. Under full load conditions for take-off (*i.e.*, the most severe for detonation) the average mixture strength of the mixture leaving the carburettor would be about 10 to 15 per cent. rich, and it seemed unlikely that the differences in mixture strength between the weakest and richest cylinders would exceed 10 per cent. Therefore the weakest cylinder would receive a mixture about "correct" mixture strength,

[42] Ice Formation in Carburettors, by W. C. Clothier, M.Sc., Wh.Sch., A.M.I.M.E. Journal of the Royal Aeronautical Society.

and generally speaking this was found to be about the mixture strength at which maximum detonation occurred, and which was the mixture strength employed on most fuel testing engines.

The author regretted that he had no information available showing the influence of combustion chamber fittings (pressure gauges, indicator units, thermo-couples, etc.) upon combustion in full-scale aircraft engines. Under most favourable conditions it could only be hoped that they would have no effect, but generally they were likely to encourage detonation by reason of the interference they introduced with the combustion chamber cooling arrangements.

With regard to the use of cracked gasolines for aircraft engines, the author said that the only danger from these was in the event of their being unstable. Under those circumstances gummy substances might form to cause undesirable deposits on inlet valves and stems, and if allowed to stand for any length of time might also obstruct carburettor jets and passages. It is now possible to produce quite stable cracked gasolines; indeed, most motor gasolines to-day contain appreciable proportions of cracked products. Therefore, there seemed little reason for the continued preclusion of cracked gasolines or blends of them for aviation purposes.

Replying to Miss D. Spicer, with a fuel distilling 25 per cent. to 75°C. there should not be any difficulty in starting under normal conditions. Obviously, the fuel referred to was a normal motor gasoline which at low atmospheric temperatures would give inferior starting to an aviation gasoline. With regard to the formation of gum in carburettor jets, the author said this was extremely unusual as, as already stated in reply to Dr. von Philippovitch, although all high grade motor gasolines of to-day contain a certain proportion of cracked gasolines, they are usually so stable that troubles from gum formation were unlikely to develop. It would have been extremely interesting to have analysed a sample of the gasoline in the machine's tanks at the time.

He thought the indicator referred to by Mr. Stansfield was likely to prove of considerable value in the study of detonation. The method of control, *i.e.*, selection and amplification of any part of the diagram, was particularly interesting and valuable. It was, of course, unfortunate that these instruments needed some connection with the combustion chamber. In the case of modern aircraft engines fitted with electric starters it was difficult to make provision in the cylinder head for the indicator unit. This objection also applies to the " Detonindex."

The author strongly supported Mr. Stansfield's suggestion that type test fuels should be at least one to two octane numbers lower in anti-knock value than the minimum laid down in the specification for the service fuel. There are likely to be other important advantages to be gained by such a policy in addition to those mentioned by the speaker.

In reply to Mr. Banks, thermo-couples projecting into the combustion chamber could obviously only be used on purely experimental engines. On a high temperature engine in particular any projection was likely to upset completely its detonating characteristics. Curiously enough, the projecting thermo-couple used on the E.35 engine for the experiments described in the paper did not appear to have any such effect. With regard to the measurement of piston temperatures, some additional work on this subject had been carried out and the results given in a further Appendix (No. 8) to the paper. There did not seem to be much hope of measuring piston temperatures when running, even on single-cylinder aircraft engines.

It was not really intended in the paper to suggest the use of the exhaust gas thermometer as a standard " detonation indicator " in aircraft engines. The many disadvantages, as pointed out by Mr. Banks, were too great. The objections raised could be overcome relatively easily in the engine laboratory and the information obtainable by this method was claimed to be of considerable value. It was agreed that the figures 15 to 20 per cent. rich given for the maximum

power mixture strength may be on the high side for modern supercharged engines. Nevertheless, the fact that even 5 per cent. increase in richness is necessary indicates the need for further improvements in distribution efficiency.

The information given by Mr. W. W. White relating to the latest work of the C.F.R. Aviation Sub-Committee was extremely interesting. The failure of the C.F.R. engine to give satisfactory correlation with benzol mixture was rather more serious as far as supplies in Europe were concerned than in the U.S.A. However, the next published report of the C.F.R. Aviation Sub-Committee was awaited with considerable interest by many.

A " flying laboratory " on the scale suggested by M. Pontremoli is perhaps rather Utopian, although much useful information could be obtained from it. Its chief use would be to enable some correlation to be established between the fundamental experiments carried out in engine laboratories and service flying conditions.

The work of MM. Serruys and Pontremoli has already added considerably to our knowledge of the process of combustion and detonation in engine cylinders, and the author expressed his thanks for the interesting contribution to the discussion made by M. Pontremoli on this occasion.

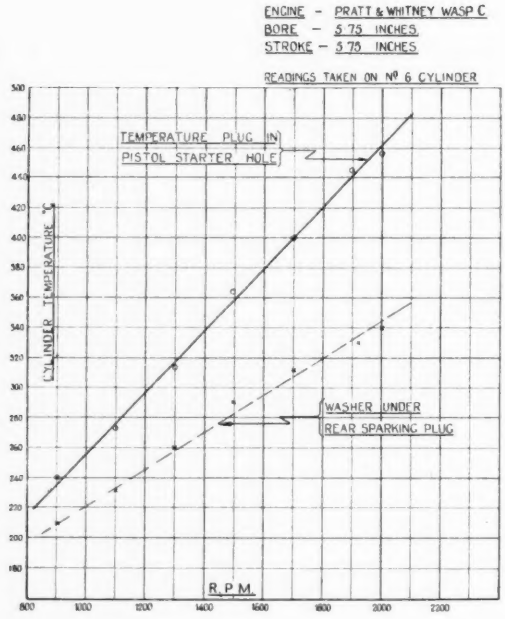
In reply to the written contributions, the author communicated as follows:—

The author agreed absolutely with Mr. Constant's remarks regarding the measurement of detonation by its temperature effects rather than by its noise or " pin bouncing " capacity. It was for this reason that some attempts had been made to ascertain what relation, if any, existed between a cylinder head temperature (or the temperature of some part likely to be adversely affected by high temperatures) and exhaust gas temperatures. Generally speaking, exhaust gas temperatures are easier to measure than cylinder head or piston temperatures, and in the experiments described in the paper it was shown that they gave a much wider spread than cylinder head temperatures. It was freely admitted that the temperatures recorded—for want of a better term—were as Mr. Constant said, some kind of average between the flame and head temperatures. The thermo-couple giving these temperatures was used for the reason that it was more sensitive to temperature changes than a couple close to the cylinder head walls, the temperature variations of which are damped by the cooling water. The increased sensitivity of the projecting type plug has since been demonstrated on an air-cooled engine, the K.L.M. very kindly carrying out experiments on one of their Pratt and Whitney C.I. Wasp engines, the results being shown in the following figure.

With regard to Mr. Constant's query relating to Mr. Beall's formula, the author had received the following comments from Mr. Beall:—

> " The formula is empirical. It is, however, based on a large number of tests where conditions were maintained constant with the exception of single variables and each detail of the formula constructed to conform in such a way as to justly evaluate the effect of the variable.
>
> " The factors used in the formula are, of course, obvious and the method of its use was developed through experience with all of the data we collected in addition to the special test runs from which the formula was constructed."

The author thanked Mr. Clothier for pointing out the discrepancy in the data given in the paper. The dew points referred to in the paper were determined for 100 per cent. fuel vapour, and, as Mr. Clothier points out, the dew point temperature is very much dependent upon mixture ratio. The high degree of heating necessary to obtain complete vaporisation of a gasoline is, of course, due to its latent heat and this only varies very slightly for all types of gasoline irrespective of their dew points. In the light of Mr. Clothier's recent work on ice formation in induction systems, the method developed by him certainly offers



the advantage of giving more certain and positive indication of ice accretion than the induction pipe thermometer.

With regard to Major Bulman's remarks about the relative cost of fuels to specifications D.T.D. 224 and D.T.D. 230, the author would like to mention that the two fuels in question constitute rather a particular case, since although the latter specification calls for a fuel of higher octane number, it allows the addition of T.E.L. to such an extent as to increase considerably the number of sources from which the basic fuel can be produced In the author's opinion a point has now been reached where the octane number of fuels can only be increased by the adoption of more complicated and expensive manufacturing processes, and the indication is that the very high octane fuels of the future will definitely be more expensive than present-day gasolines.

The PRESIDENT: He had always regarded it as being most unfortunate that the petrol engine was wrapped up with aviation. Having been weaned on petrol, he could not be accused of not having a very sincere affection for the internal combustion engine in all its walks of life; but nothing could be more inappropriate than to fly about with an engine consuming a most inflammable fuel, and he had hoped that within a few years the use of the petrol engine for flying would be all over, and that they would use Diesels, and possibly steam. But along came the scientific people, bringing high octane numbers that had given the petrol engine another lease of life.

But the problem was one of immense complexity. The Society was grateful to him for the serious and hard work he had devoted to its preparation and for the charming way in which he had presented it.

The vote of thanks, proposed by the President, was accorded with enthusiasm, and the meeting closed.

The 593rd Lecture delivered before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

An ordinary meeting of the Royal Aeronautical Society was held on Monday, April 15th, 1935, in the Lecture Hall of the Institute of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2. In the chair, the President (Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.P.).

The PRESIDENT: It was now over twelve years since they had had the pleasure of listening to Captain de Havilland on aeronautics, and here he was, looking as young as ever. It was remarkable to look at him, and realise how young all this movement was, because Captain de Havilland was right in at the birth of flight; he assisted almost at its accouchement, and he was the real father of the light aeroplane. Efforts had been made to persuade him year after year to give a lecture, and at last they had succeeded. He was the only holder of the British Gold Medal for Aeronautics of the Society—one of the highest honours they could pay him—and they welcomed him back that evening to discuss a subject of which he was indeed a master.

Captain G. de Havilland then delivered his lecture on "Commercial Aircraft."

COMMERCIAL AIRCRAFT

BY

CAPTAIN G. DE HAVILLAND, F.R.Ae.S.

The present stage in the evolution of commercial aeroplanes brings questions of speed and load into prominence, and it is hoped that an attempt to look at these things from a designer's point of view may be justified.

An aeroplane at first glance might appear to be an uneconomical vehicle. It may have over 100 h.p. installed per passenger, and this gives an expensive impression. The other side of the picture is that aeroplanes can achieve over 60 passenger miles per gallon of petrol at a higher speed than any other form of transport. This consumption figure is a very good criterion by which to measure all the other running costs. The expensive appearance of the aeroplane is due to the large amount of power installed in relation to its carrying capacity. This appearance becomes reality unless the great mileage per annum of which the aeroplane is capable is to some extent achieved, and the fact that the conditions under which British (including Empire) aviation has developed have not so far favoured intensive day and night flying, has had its effect on design. In the past it has been necessary to aim at simplicity, low power, light loading, and low cost. Types embodying these qualities have achieved the objects for which they were produced, and have played a very great part in spreading aviation over the world.

There seems to be a general, though in this country a rather tardy, recognition of the vast possibilities of civil flying which may result in the provision of well-equipped routes and the other facilities without which high-speed transport cannot come into being. This will have an important effect in freeing design from the limitations caused by undeveloped conditions of the route, it

will alter the economic basis of air transport, and justify the use of the really high-speed machine.

The time, therefore, seems opportune for reviewing some of the principles which underlie design—more particularly those which govern speed and economy of transport.

Effect of Increasing Design Speed

The familiar law that speed increases as the cube root of power, so that doubling the power only gives a 26 per cent. increase in speed, does not directly govern the design problem, for the first essential in comparing designs is to stipulate that each one considered must be loaded up to the same take-off facility, or some similar criterion such as the ability to fly with one engine out. For the present purpose the take-off over the screen will be used.

The general effect of increasing power to get speed may be seen by considering some particular aeroplane to be redesigned for an increase of power, but with the main dimensions unaltered. With the greater power the total weight for take-off can be increased, although the new w./h.p. cannot be quite so great as the old because the loading has increased. Of the increase in weight, some must be set aside for engine and fuel, some for increased structural strength, and the balance is available for pay load.

We have on one side of the account a bigger pay load and a higher speed, while on the other is a larger h.p. and therefore a greater fuel and maintenance cost. The fact that the speed has only increased as the cube root of the h.p. is offset by the greater load carried.

Naturally these clear-cut cases do not occur in practice. It would, for instance, in the above example be necessary to lose a little speed by increasing the size of the fuselage to accommodate the bigger load. When all these things are taken into account, however, it will be found that increasing the speed does not involve higher running costs expressed as ton-miles per gallon, at any rate within the limits imposed by practical considerations. The wing loading will, however, progressively increase as the design speed is increased if the ability to take-off is the same. There does not seem to be any difficulty yet in getting into aerodromes with the devices now available. Wing loadings of well over 20lbs. per sq. ft. with heavy span loadings are quite common, and the landing qualities of such machines are well spoken of.

Summing this up so far, we have said that an increase of power in an aeroplane of given size enables a greater total weight to be taken over the screen, that after providing for the increased weight of power-plant and fuel there remains a margin for increased pay load which is sufficient to balance the relatively low increase of speed, and thus preserve the original ton-mileage per gallon of running costs. If this balance is preserved it is of the greatest importance, for it means that high speed can be designed for without increase of running costs, and would only be limited when the resulting high wing loadings cause trouble in getting into aerodromes.

The underlying features involved are then as follows:—

(1) The combinations of power and surface loading which will ensure a given take-off facility.

(2) The speed which can be expected from the combination selected having regard to size in relation to power for a given degree of cleanness.

(3) The percentage of the total weight which will consist of aircraft structure, as determined by the size of the aeroplane and its loading.

Speed and Commercial Merit are Compatible

Estimation of these factors is necessary to determine the nature of the variation of load carried with the speed of flight if take-off remains the same.

It would be easy to take examples worked out on this basis and to examine the relationship of speed and load carried, but since every designer has his own method of arriving at these things it is simpler to state that if any examples are so worked out they will show that the pay load decreases very roughly *pro rata* with the increase of design speed, thus leaving the commercial performance unaffected (this being measured by the product of speed and pay load or ton-miles) and making high speed an additional asset for which no payment in ton-mileage is incurred. This result will be approximately arrived at whatever method is employed in estimating the quantities involved. It may then be asked why other results have been shown, for it would be a serious reflection on the validity of any conclusion if different individuals could produce answers which were different in kind to a question in which natural laws were to some extent involved. I think the reply to this is merely that my basic assumption has been that all aeroplanes considered must be so designed that they take-off equally well, and that those who have expressed opinions on the cost of speed would have arrived broadly at the same conclusion if they had used the same basic assumption.

It follows, of course, that on this basis the wing loading will continually increase as the design speed is increased, and will eventually limit the speed. If speed and load carried can be exchanged over a wide range without altering the ton/miles per gallon, it would be interesting to see how this would work out in practice. Assuming a machine of moderate or slow speed, would it pay to take half the load at twice the speed? Operators will be able to say to what extent terminal delays affect the problem. It largely depends on the sort of air route considered, but speed is of such high value that the disadvantages would have to be very real to warrant the use of the slower type.

The fact that structure percentage increases with size and diminishes with loading has sometimes been doubted. The existing sliding scale of load factors which is arbitrary and not necessarily permanent masks it to some extent. While the present régime in which the bulk of the weight is carried in the middle of the aeroplane continues, however, it is inevitable, and can be plainly demonstrated by examples which exhibit the relation of the structural percentage to the total factored weight (*i.e.*, the " failing " weight) and its variation with size.

The increase of structure percentage with size has the effect of limiting the combinations of power and surface loading to the fast end of the scale in the case of large aeroplanes if a good transport efficiency is to be reached—a tendency which is very evident to-day.

Practical Examples

Passing now to the manner in which these considerations are wrapped up in practical questions of design, an examination of types of transport aeroplanes in extensive use to-day will show that from 40 to 60 passenger miles per gallon are achieved and that there is no discernible departure from this for aeroplanes of under 100 m.p.h. to over 200 m.p.h. cruising speed, provided the load carried is referred to the same take-off facility over a screen. If the criterion used is a less artificial one of, for instance, ability to fly with one of two engines out, or rate of climb, or reserve power near the ground, then the faster machines will be found to have a greater passenger mile per gallon performance than the slow. It will be realised that there are obvious difficulties in comparing many types together, and unless they are all designed to the same take-off, some adjustment is needed. It will be found, however, that no advantage in running costs is disclosed by low speeds and large paying loads. The faster machine must, of course, have a greater initial cost per seat, and this must always be the case where more power per passenger is installed. The extent to which this matters

will be determined by the mileage per annum which can be achieved, and this in its turn by the ground organisation for day and night flying, the traffic density, and so on.

I am not qualified to deal with transport questions, except in so far as they are wrapped up with design, but simple arithmetic will show that the initial cost per seat can be allowed to increase in direct proportion to the speed (for a given number of hours' flying per annum) without advancing the obsolescence charges or any others which depend on the first cost of the machine.

When we think of British commercial flying, which has been either slowly working up traffic unassisted or has been pioneering once-a-week services over desolate regions without mail contracts, we see that the only possibility has been to use the slower types which are of low first cost per seat. It is perhaps equally evident why the natural development in America has been towards the high-speed highly loaded type which, under American conditions, can rapidly reduce obsolescence or depreciation charges to proper proportions.

The important point is that there is little difference in running costs.

A given load can often be more efficiently carried in two machines of moderate size rather than in one big one owing to structure weight. This question is complicated by the amount of fixed equipment which must be carried and which is variable on different services. Where a restaurant and a considerable crew is carried it is clear that the passenger capacity cannot be too small, though it will pay to go for high speed and moderate pay load more and more as the size of the unit increases.

The process of reducing size and increasing speed can be carried further in single than in multi-engine machines, because in the latter there is a fixed amount of engine nacelle, fuselage, etc., which is of considerable resistance, and it would not produce a proportionate increase of speed to leave this alone while reducing too much those parts of the aeroplane concerned in lifting the load. It has, however, been found in practice that heavy loadings and high speeds are practicable up to a considerable degree for twin-engine machines.

The gradual working up of traffic without a basis of fixed contract loads or other Government assistance is a slow process which incidentally has developed further in this country than elsewhere. High speed transport must take a long time to develop under such conditions, and operators who are feeling their way cannot be expected to embark on the larger capital cost necessary to get high speed without being able to foresee the traffic which would follow the organisation of routes.

Variable Pitch Propellers

I should like to say a few words about the variable pitch propeller, as this has an overwhelming influence on the possibility of making fast and economical aeroplanes. The propellers of slow machines are working under tolerably good conditions during take-off. The blades are not stalled and the r.p.m. are not unduly low. As the design speed increases the blade angles have to be made relatively coarser to deal with the cruising speed, and this leads to stalled blades and low r.p.m. during take-off. Variable pitch enables these angles to be reduced so that full r.p.m. and efficient blade angles may be used during take-off. Were it not for this, 50 per cent. of paying load might have to be omitted in high speed machines to secure the necessary take-off, apart altogether from the difficulty of getting engines to stand up to low r.p.m. and full throttle. It would be difficult to overestimate the importance of this device for commercial flying. Even with engines which have been developed only for fixed pitch propellers and have no other rating, it allows the prescribed power to be taken from the engine without exceeding the prescribed r.p.m. up to considerable altitudes, thus permitting much higher cruising speeds for the same maintenance cost.

Supercharging

The question of supercharging engines must be mentioned. It is necessary and legitimate to take more power from an engine during the short period of take-off than for cruising. If the cruising power were 70 per cent. of the take-off power, full throttle could be used at 10,000ft. for cruising and reduced throttle below that height, but up to 10,000ft., in this case, there would be no use for a supercharger unless it was necessary to take-off from high altitude aerodromes.

This, however, is not the whole story, for by suitably arranging the compression ratio, etc., engines can be " ground boosted " up to considerably greater powers than the same engine without a blower. This is really equivalent to installing a more powerful engine, but is a much lighter way of doing it. It will be seen that a supercharger which did not enable the maximum power to be developed for take-off would be of limited use commercially.

The "Comet" as an Illustration

Reference may be made to the " Comet," but only in so far as it illustrates the arguments I have used, because a paper on the subject has already been read before the Society.

The " Comet's " engines may fairly be described as being of a relatively heavy commercial type. When fitted with V.P. propellers, air pumps for instruments, etc., they weigh 2.3lbs. per h.p. The other things tending towards weight are the flaps, retractable undercarriage, and the fact that the wing is a full cantilever of small thickness. These are, however, overbalanced by its small dimensions and high loading, both of which permit of a low structure weight (26½ per cent.) which, together with its speed, give it the extremely high value of 9.6 ton-miles per gallon for 500 miles range, at its operating height of 10,000ft. There are obviously things which prevent this machine being directly compared with commercial aircraft. It can, however, be looked upon as an interesting illustration of what has been said, for whatever deductions must be made because it is not a passenger carrier, could not possibly do anything but leave it as an example of low running costs coupled with high speed.

Alternatively the " Comet " might be regarded as a scale model for a commercial aeroplane. If the machine was scaled up to four times the power—still quite moderate—the fuselage would become a commodious cabin without any alteration of proportions. Some loss in structure weight would be incurred, but there is something in hand in engine weight, and no doubt an outstanding high speed aeroplane could be developed on these lines.

Take-off and Landing Regulations

I should like to say a word about one aspect of the regulations covering take-off requirements. The present take-off regulations have served, and no doubt will serve, a useful purpose, but the high speed, highly loaded aeroplane has, for the same screen performance, a much higher ceiling and therefore reserve power. Now if long oversea journeys are wanted at high speed in the future it would be easy to license aeroplanes for the use at some greater weight for one particular aerodrome with sufficiently long runways and make the safety requirement a minimum ceiling or rate of climb. Some such course would appear to be more economic than limiting the load or the range to comply with a requirement which would merely adversely affect the utility of the aeroplane in the particular circumstances. The regulation for landing run may soon be restrictive also for high speed aircraft. It will no doubt require examination.

Passenger Accommodation

The passenger is the ultimate user and it is essential that his point of view is kept in mind throughout the design of the machine. Passenger comfort is chiefly dependent on the type of seating, cubic capacity of cabin, noise and ventilation. Having travelled to East Africa and back last month by Imperial Airways, it was interesting to get the passenger's impression over a long route which varies so remarkably in climate and scenery. The high degree of comfort of the machines in use—the Short " Kent " and Handley Page " Hannibal "—is well known, and therefore I would only mention in a general way the features which impressed one as being of greatest importance from the passenger's point of view.

Design of chairs and cushions must be carefully thought out. The position and design of windows is of great importance because air travel gives the passenger an extensive view of a slowly moving and ever changing landscape. No other method of travel gives this. The clear large window of correct height does much to relieve the tedium of a long journey.

It is doubtful whether much can be done to eliminate noise by modifying the engine or exhaust system. Geared-down propellers are, however, a great advantage from this point of view, and their relatively quiet running is sufficient to warrant their general use. A position of engine and propeller where they are screened from the cabin by the plane structure is the most effective way of reducing noise. This is borne out in the case of the " Kent " and the " Hannibal " types, both of which have reasonably quiet cabins.

Ventilation is usually good on modern air liners, and is not a difficult problem. The separate ventilator for each passenger, which is now in general use, seems to give the best results.

Heating in some cases is inadequate when flying at high altitude in cold weather. There is unfortunately plenty of heat going to waste from the engines, and it is only necessary to use more of this to give suitable cabin temperatures under all conditions.

Construction

There is a tendency to look upon metal as a more suitable material than wood, and any improvements in the strength/weight ratio of materials are to be looked for in metal. On the other hand, years of actual service under extreme climatic conditions have proved that wooden construction gives little trouble, cannot suffer from the effects of fatigue, and is cheaper to produce and repair.

The Comet wing is an example of a new form of wooden construction, where spruce planking is used to form a thick stressed skin which gives a very robust and durable structure and eliminates fragile sections which are liable to damage. It would seem that at the present time the material used in construction has little bearing on the performance of the machine, and is chiefly governed by the price the operator is prepared to pay.

Methods and materials of construction are naturally a subject for a separate paper, and is only being touched on in a very general way here. The point I wish to put forward is that for machines of moderate and small size, wood has been adopted primarily for reasons of cost and speed of production and has proved safe, light and reliable. The time has not arrived when the use of metal is warranted owing to what is known as mass production. Few will doubt, however, that metal or possibly synthetic material will eventually be used universally, because it is in this direction we must look for lighter construction. I believe the wooden machine still has a long life before it.

Monoplanes and Biplanes

The question of monoplane and biplane has often been debated. It is really wrapped up with the conditions under which the aircraft is to operate.

One way to sum up the situation is to say that biplane construction is lighter and the monoplane faster, but in making any such generalisation the basis of comparison at once wants defining. It is easier to take-off with a large load on the biplane, because light loading is more easily obtainable. This has tended to make the biplane well suited to operations from poor aerodromes and high altitudes, and under conditions generally where light wing loading is called for. It cannot be said, however, that one is " better " than the other. The modern high-speed aeroplane has become quite generally a low wing cantilever monoplane. The relatively small dimensions associated with high speed permit this construction without feeling its higher structure weight too seriously, and it lends itself well to retractable undercarriages. This type has been developed very much in America, where the conditions call for machines of moderate size and high speed.

Large Aeroplanes

The very large aeroplane presents another problem. It would be a highly desirable type for some present routes and many future ones. The great problem is the increasing structure percentage with size. Hitherto this has been countered partly by the lower load factors required, and partly by increased wing loading, especially for seaplanes. An end must, however, come some time to increases of loading, and then the problem of distributing the load span-wise will arise, as this would be an effective way of keeping structure weight within bounds. A rather drastic departure from orthodox designs would be necessary in carrying this process very far, but it has already been done to some extent—particularly in the Do.X. Although superficially some big aircraft do not seem to have run into this weight increase very badly, it will be found that they all conform pretty well to the effects of size and loading when proper allowance is made for load factors and so on.

All this is perhaps looking rather far into the future when so much remains to be done within the present régime of design. It is, however, as well to glance at this problem, as the large aeroplane will be wanted as soon as it can be obtained efficiently, and it seems a pity that each step in that direction is secured by a sacrifice—whether visible or concealed—of valuable load capacity.

Evolution of Commercial Aeroplanes

If we take a rapid glance at the evolution of commercial flying in the last 10 or 12 years, we see that from the beginning of the period there has been a definite and sharp break away from the military evolution. The two lines of development might be described as getting the utmost return in performance for every horse-power developed in the cylinders on the one hand, and getting the utmost performance regardless of the power used, on the other, or military side. Rapid steps in the required direction were made in successive types of small aeroplanes until their transport performance was about the same as a motor car —say 20 miles to the gallon with three people up—but at a far greater speed. In a few years these small aeroplanes have surpassed the speed of their single-seater fighter ancestry with about one quarter of the power. They have done much important work in making flying possible all over the world by all sorts of people and they have set a standard of economy which can be used for large commercial aircraft.

This evolution has taken place in a very steady and healthy manner and is responsible for the fact that there is more purely commercial and unsubsidised flying in this country than anywhere else. This progress by means of small and continuous steps, without too great a commercial risk, would have been the best and surest way of leading—as it would have—to high speed transport. Such development is always linked with intensive use and this link is absolutely necessary both for progress in design and in supplying a spur to research.

Now if everyone had done the same thing the position in this country would have been excellent, but when other countries are spending large sums on ground organisation, mail contracts, etc., they are obviously able to make very rapid progress.

Everyone must admire the almost spectacular technical progress made in America recently. This progress in design and research has been intimately connected with intensive experience on the air lines. Progress in commercial flying can take place in no other way. Isolated prototypes or technical achievements which are not directly linked with continuous hard use can play only a small part in furthering air transport. When ground organisation is thoroughly developed and there is a solid foundation of mail or other contracts on which to base services, all the rest will follow. These are the conditions under which rapid progress in design and research will take place and for which there is no substitute. Unassisted British operators are putting up a good fight to find traffic under adverse circumstances among which must be numbered a crushing tax on his fuel if, operating internally, and often very high fuel costs due to transport charges if operating overseas. There is every hope, however, that the growing recognition of the value and importance of air transport will assure this country the opportunity of keeping in the forefront of technical progress.

Appendix

Fig. 1.—The curve marked F.P. on Fig. 1 shows a relation between span and power loadings which determines the total weight at which an aeroplane fitted with fixed pitch airscrews will comply with the British and I.C.A.N. normal take-off requirements (66ft. height attained after 656 yards from rest). The curve marked V.P. shows the same thing when fitted with variable pitch airscrew.

Aeroplanes whose plotted points lie above the appropriate reference line would experience more difficulty in complying than those below, conversely, those below might be expected to clear the screen by some margin; in such cases the excess height above the screen, where known, is indicated in brackets after the name of the aircraft.

The curves are purely general, and only take account of the most important factors influencing take-off and climb. For instance, aerodynamic cleanness would have some influence on the position of the reference lines.

In general, aeroplanes whose plotted points lie toward the right-hand side of the figure would be fast; and those to the left, slow. The effect of high top speed on airscrew characteristics at take-off speed in their relation to take-off has been included in the curves.

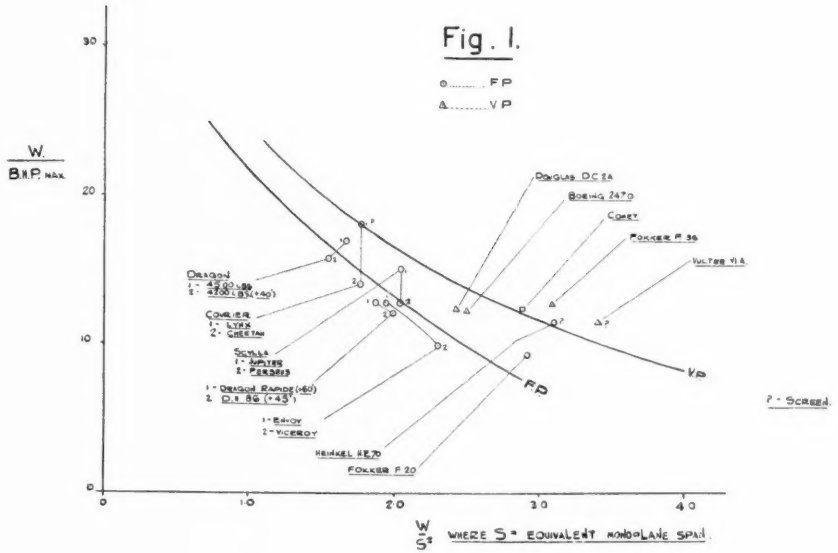
Fig. 2.—Speed depends closely on frontal area per h.p. for a given degree of cleanness. Span is here used as a measure of frontal area. This is particularly convenient because span also determines fairly closely the w./h.p. which can be lifted over the screen. This figure is thus linked with Fig. 1 through span and h.p.

Fig. 3.—Same as Fig. 2, but illustrates the applicability of span and h.p. as a measure of speed over a wide range of speed, and for widely differing types of aeroplanes.

Fig. 4.—Variation of structure weight with size and loading. The curves are strictly speaking empirical, being based on a large fund of well attested data for widely different types of aircraft. They are also in close agreement with theoretical laws for various types of structural members.

Figs. 1, 2 and 4 embrace the three most fundamental and interdependent factors in the problem under discussion.

Fig. 5.—Fig. 4 expressed in a more tangible form showing separately the effects of loading and size.



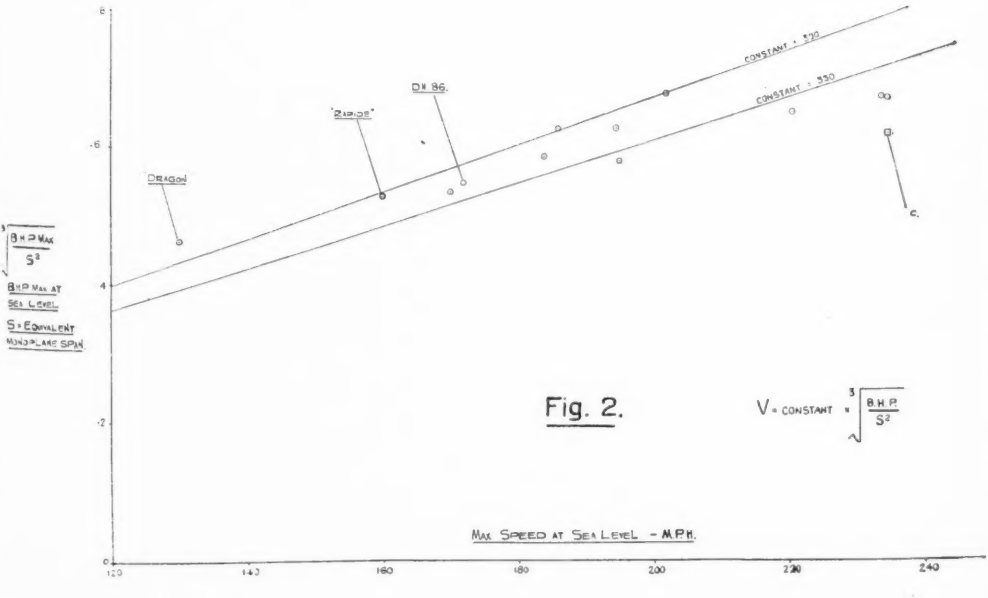


Fig. 2.

$V = \text{CONSTANT} \times \sqrt[3]{\frac{B.H.P}{S^2}}$

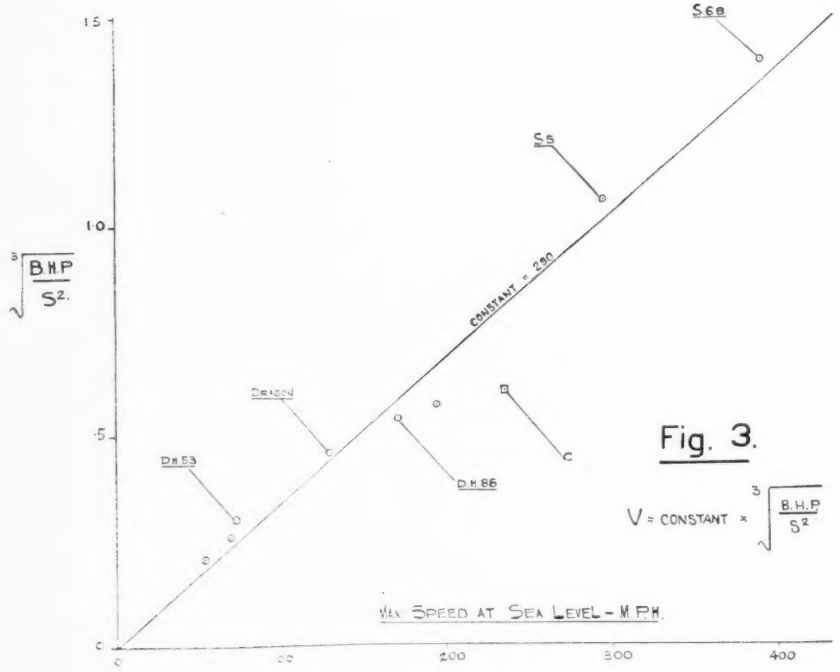

S.68
S.5
CONSTANT = 290
DRAGON
D.H.53
D.H.86
1·5
1·0
·5
0
100
200
300
400
MAX. SPEED AT SEA LEVEL - M.P.H.
V = CONSTANT × ∛(B.H.P / S²)

Fig. 3.

Fig. 4.

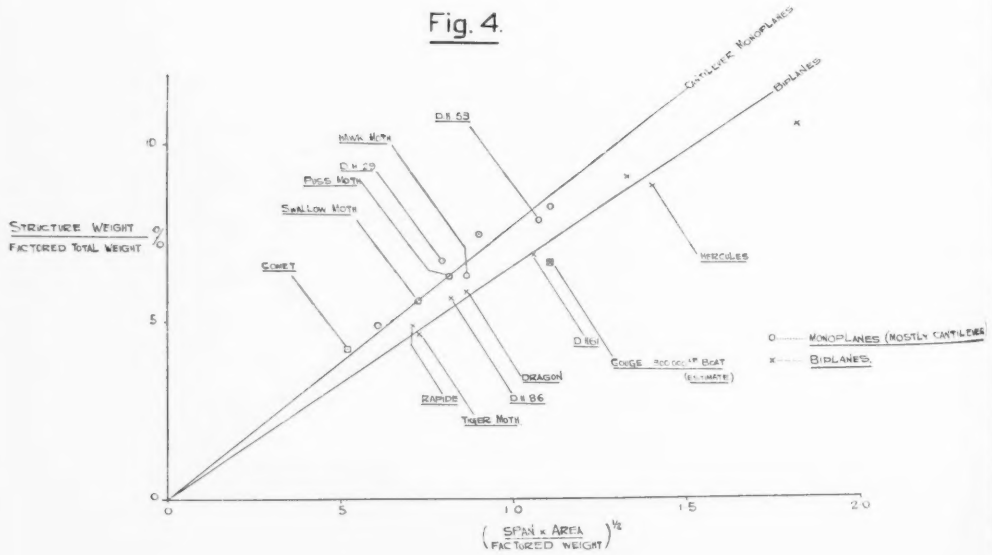

CANTILEVER MONOPLANES
BIPLANES
D.H.53
MOTH MOTH
D.H.29
PUSS MOTH
SWALLOW MOTH
COMET
HERCULES
D.H.61
COUGE
DRAGON
D.H.86
RAPIDE
TIGER MOTH
STRUCTURE WEIGHT / FACTORED TOTAL WEIGHT %
10
5
0
0
5
10
15
20
(SPAN × AREA / FACTORED WEIGHT)^½
MONOPLANES (MOSTLY CANTILEVER)
BIPLANES.

Fig. 5.

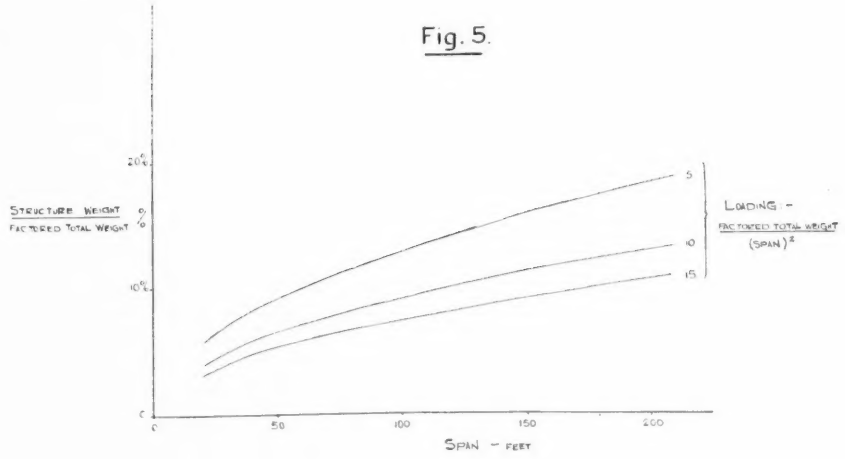


FIG. 6 contains actual values of the ton mileage of pay load per gallon of fuel when carrying fuel for a range of 550 miles for a number of current types of commercial aeroplanes.

It should be borne in mind that a number of important factors influencing the ton-mileage/gallon are not the same for all the aeroplanes represented. For instance, some have V.P. airscrews and some have not, some clear the screen by a large margin and some do not.

FIG. 6.

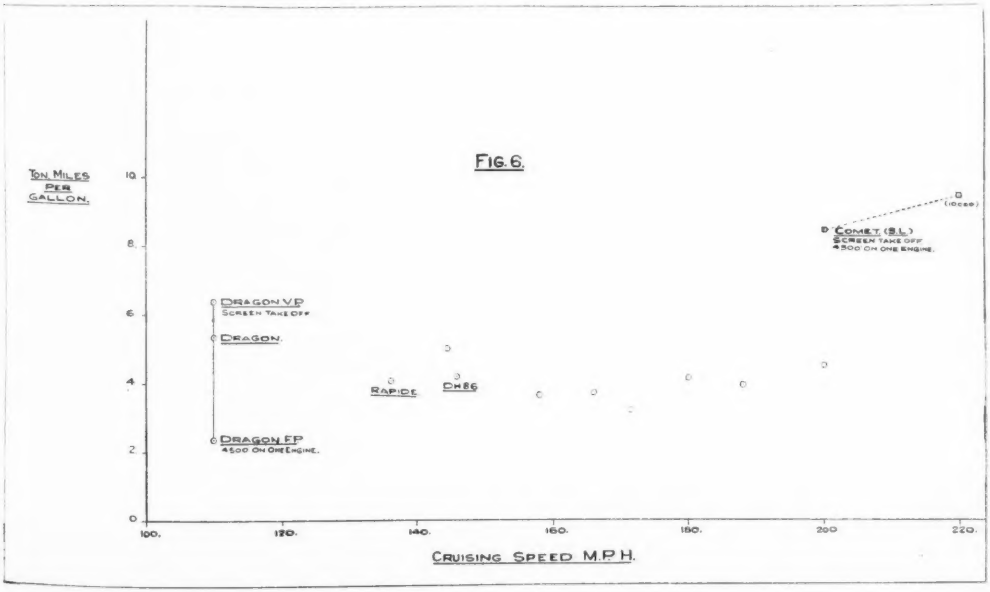


FIG. 7 shows the thrust h.p. available at various speeds for either a Fixed Pitch or a Two-position Variable Pitch airscrew installed in an aircraft having a maximum speed of 200 m.p.h. A h.p. required curve is also indicated.

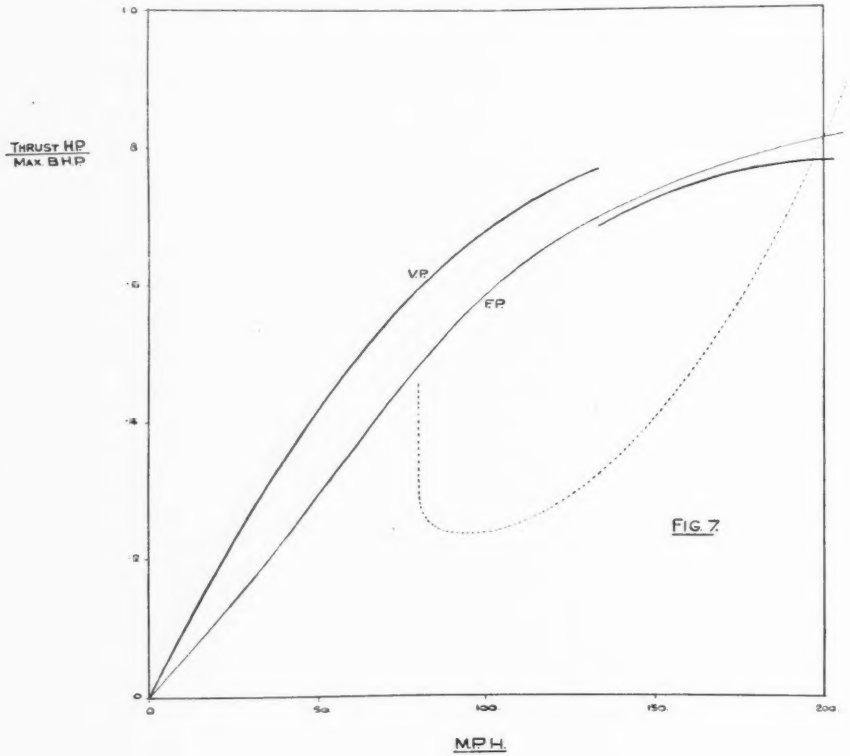
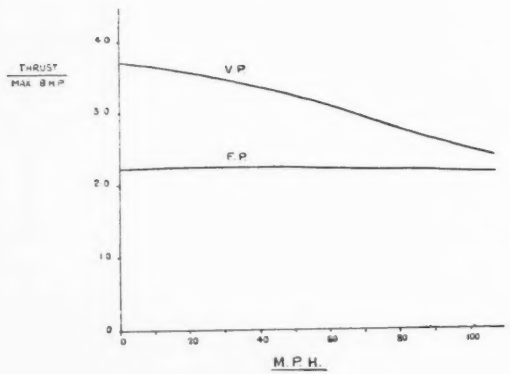


FIG. 7.

FIG. 8



The V.P. airscrew is assumed to be designed for a speed of approximately two-thirds maximum, this being about the best compromise between the take-off and speed conditions; there is a loss of maximum speed with the V.P. airscrew of approximately 3 m.p.h. compared to the F.P. airscrew, on the other hand, it is possible to lift $1\frac{3}{4}$-2lbs. more pay load per h.p. over the screen with the V.P. airscrew, with consequent better ton-mileage/gallon.

FIG. 8 shows the curves of Fig. 7 plotted in the form of thrust (lbs.) per max. b.h.p. over a range of speed covered by the take-off and climb.

DISCUSSION

Mr. S. H. EVANS (*Member*): Captain de Havilland had said that " There is more purely commercial and unsubsidised flying in this country than anywhere else." The speaker, who had spent the past six years in California, did not think that was quite true. It was his impression that there was probably more unsubsidised flying in that one State of America than the whole of Great Britain altogether. He thought that England of all countries had pioneered the State-supported flying club scheme of making a nation " air-minded." Furthermore, he believed that Captain de Havilland would readily admit that the D.H. " Moth " really owed its commercial existence to a great extent to its wide acceptance and popularity with these same subsidised flying clubs up and down the country.

The lecturer also referred to the spectacular technical progress in America, rather suggesting that such progress was due primarily to Governmental subsidy in the form of generous air mail contracts. The speaker did not believe that this commonly accepted apologia for their own shortcomings was a very honest one; neither did it redound to their reputation as a nation of good sportsmen on the other side. No doubt, air mail contracts to the American operator—each competing against the other—had helped the situation, but he had never heard of an American transport operator demanding external control wires, and other such bird-cagery, in the interests of his maintenance staff. Judging from his own observations in the States, he would suggest that American technical supremacy at the present time was largely a measure of the American attitude towards industrial research, and the mental alertness of the American designer in applying these results to his current design, rather than waiting for the other fellow to discover the snags. They were here essentially a nation of compromisers, and while complacently casting their bread upon the waters and returning after many days with half a loaf, their American friends were impatient for new bread as soon as baked; while they in this country made every sort of excuse for their leisurely progress " from precedent to precedent," the American designer had gone right out for aerodynamic cleanness, realising that the elimination of parasite drag was an economic first principle and not merely an idealistic dream.

After all, the genesis of any new aircraft type was fundamentally an aerodynamic conception and there could be no possible excuse for the kind of subsidised monstrosity seen in this country to-day, a forest of struts and wires all charging the breeze and burning up pay load while taking four engines for a ride, as some of his American friends had jokingly suggested. He believed that the Americans had shown them the way, first with the Boeing, and more recently with the Douglas " DC-2." In his view, the " Comet " design was a delight to the eye, a perfect example of engineering judgment and aerodynamic conception for the job in hand. Its characteristics should be prescribed three times daily as a corrective for all designers suffering from aerodynamic astigmatism, with perhaps an extra dose for the technical advisers of our own particular brand of subsidised monopoly when they lay down their next design specification.

Major GREEN (*Fellow*): It was a very long time since he was first associated with Captain de Havilland, very near the beginning of flight; he had had the great pleasure of working with him two or three years before the war, and it was with Captain de Havilland that he had made his second flight. He wished to congratulate him very much indeed upon a valuable and inspiring lecture. There were one or two small points on which he did not quite agree, but it was an excellent thing to hear from such an authority that they could expect to go quite fast at no greater cost per ton mile than had to be paid for travelling at something like half the speed. That, if true, was an extremely valuable statement, and should inspire great hopes for rapid development of civil flying.

Turning to the lecture itself, Captain de Havilland said that the consumption figure per ton mile of pay load was a good criterion by which to measure the other running costs; this is the same as saying that the horse-power used was a good criterion because the petrol was obviously proportionable to the horse-power. He says that the " Comet " (in Fig. 6) at 200 miles per hour has a remarkably good petrol consumption. The speaker suggests that this is not altogether because the " Comet " flies fast, but that it is due even more to the excellence of the design since the parasite drag had been kept down to the lowest possible figure.

It is fair to point out that if the " Comet " were flown at 180 miles per hour then the consumption per mile would be down by 20 per cent. and the consumption per ton mile about 10 per cent. On the criterion suggested by the lecturer the " Comet " would therefore be more economical at 180 miles per hour than at 200 miles per hour. In spite of this the speaker still believed that Captain de Havilland was right that the economic speed was about 200 miles per hour. The speaker had read a paper before the Society about a year or so ago in which he took a different criterion which he called " factor of usefulness " excluding the cost of petrol. The " factor of usefulness " would be higher at 200 miles an hour than at 180 miles per hour with petrol at the usual price. The allowance that would be made for the increased petrol used would not affect this result. It therefore seems that the criterion given on the first page of the paper is not quite the best way of examining results. In his own paper he came to the conclusion from other considerations that the economic cruising speed, not considering convenience of passengers at all, was between 130 and 150 miles per hour. That figure was obtained by excluding high wing loadings now come into use, and he was still a little doubtful whether such loadings were permissible at the moment; it would depend on the excellence of the arrangements made at the aerodromes for landing and taking-off.

In the discussion on his own paper, it was suggested by one speaker that flying at anything over 100 miles an hour became more and more costly and that one had to pay for speed. He did not agree that the economic speed was as low as 100 miles an hour, but he did think that they have to pay something for speed. With faster flight, more and more attention had to be paid to good design, because a slight error in design was much more dangerous. It would take a little time for high speed machines to work in the most economic way as experience alone will eliminate various troubles.

Another criterion was to fly with one engine cut out. Captain de Havilland showed quite clearly that if two engines only were used it was necessary to have a fast aeroplane to make it safe on one engine. If there were four engines very much more horse-power was available if one engine stopped and the same criterion scarcely applied. For most work it seems better to have four engines, or perhaps even more; there would then be a safe margin for flying when one engine failed without going quite as fast as Captain de Havilland had suggested.

He wished to thank the author for his admirable and inspiring paper.

Mr. NIGEL NORMAN (*Fellow*): The lecture conveyed a message of great hope and satisfaction to everybody connected with aviation, because from an authority

such as Captain de Havilland any information of this kind was convincing. It seemed obvious from what he had said that very great progress remained to be made in the field of commercial aviation. He wished to refer to the aspect of it which was connected with ground organisation, because that was one in which he was personally interested, and it seemed to be the one (he would suggest in deference to the last speaker) which had been concentrated upon in America and neglected in this country.

Captain de Havilland at one point in his lecture had remarked that the amount of ton miles or passenger miles flown per annum had a very great effect upon the design of the aircraft. It was obvious that if one could only operate for a small number of hours, during daylight and good weather, the machine had to be built very cheaply, and first cost economy and low running cost were of primary importance. If there could be proper equipment of air routes and aerodromes for bad weather and night flying, so that operators could rely upon a really high number of passenger miles per annum, the designers would immediately produce an aeroplane for the purpose, and in such circumstances the operators could afford to pay very much more for it.

The second point was the question of take-off regulations as affecting economy of air transport operations. Captain de Havilland suggested that if runways were longer or special aerodromes were constructed and the designer given a free hand, he would be able to produce a much more striking commercial vehicle. The speaker desired to ask Captain de Havilland if he could furnish an example. Just to state the problem we would ask what percentage increase in range could be obtained with the aeroplane which he was considering in this lecture if the present take-off requirements were doubled; in other words, with the aircraft carrying the load for a range of 500 miles, if the aerodrome dimensions suggested by the regulations to-day were doubled, and if instead of a runway of 800 to 1,000 yards it were 1,600 to 2,000. He suggested this as the simplest way of ascertaining whether an increase in runways and a relaxation in take-off requirements would help towards the commercialisation of flying.

Dr. H. C. WATTS (*Fellow*): He was not qualified to speak on a lecture on commercial flying; in that sphere he was a humble listener. But there was one point in the lecture concerning which he might be expected to say a word, namely, the question of variable pitch propellers. He did not decry in any way the great advantages which the variable pitch propeller would have for commercial flying. At the same time he did not associate himself with those wide generalisations which were at present current, and from which one would infer that every fixed pitch propeller could justifiably be replaced by a variable pitch propeller.

As he had said before in discussions in the Society, the problem was complicated, and each case must be judged on its merits. He was pleased to note, however, that in explaining the advantages of the variable pitch propeller Captain de Havilland did not follow the popular and simple explanation of such advantages, namely, that such propeller was justified by the increase in available power due to ability to use the maximum permissible revolutions upon the ground. He believed he was safe in saying that if the advantage of variable pitch propeller depended on that increase of power alone, it would be difficult for it ever to justify itself.

The variable pitch propeller derived its chief advantage from the fact that it enabled the blade angles to be reduced to such a condition that stalling did not take place in any condition of flight. It might be taken as a safe criterion that with propellers below a pitch equal to the diameter stalling did not take place over the important parts of the blade on any part of their speed range. For propellers, therefore, with pitches of less than their diameters it would be difficult to justify the variable pitch; but when the pitch was more than the diameter the propellers started to stall at low speeds, and therefore as the pitch

got higher and higher above the diameter, so the variable pitch propeller became more and more justified.

The other thing he desired to say was that he felt that finality had not been reached in variable pitch propellers. When it was realised that with a 500 h.p. engine one had to replace a relatively light wooden propeller, weighing about 100 pounds, by a variable pitch propeller weighing 250 pounds or more, and in this way lost the weight of one passenger per engine before obtaining any net gain, he felt sure that some lighter blade construction would have to be found.

He also drew attention to the fact that in Fig. 8 the thrust of the fixed pitch propeller appeared to be constant with speed, but obviously the thrust must fall to zero at some speed. He thought there was some mistake, because he was sure that no propeller had a thrust constant with speed.

Captain F. S. BARNWELL (*Fellow*): With most of the lecture he was in entire agreement. He admitted that on the question of variable pitch airscrews he did not think that Captain de Havilland had quite stated the complete case, for he had called attention to advantages, but had not mentioned any disadvantages. As Dr. Watts had just said, if an aeroplane was so fast that the pitch diameter ratio of the airscrew exceeded, say, 1 (and they were getting on to 1.6 or 1.7) the *static* thrust of the airscrew, owing to its shape, was poor, and variable pitch airscrews became necessary for good get off. But for top speed and for cruising, the fact that the variable pitch propeller was probably two and a half times the weight of the fixed pitch propeller and not of any higher efficiency was a definite disadvantage. Whilst, therefore, the great aerodynamic advantages, for get off and for climb, of the variable pitch propeller were fully realised by the aircraft designer, yet because of its extra weight, complication and cost, it must be regarded as an unpleasant necessity in other respects.

With regard to supercharged engines, he wondered whether a supercharged engine was necessarily *lighter* for the same power than a naturally aspirated one. He was not sure that that was true; it was certainly *smaller* for the same power.

He noticed, by the way, that Captain de Havilland talked of " retractable " undercarriage. He had been informed that " retractable " was bad English, and the adjective should be " retractile." It would be well to have a ruling on that point; one did not want to be inaccurate, but one hated to be pedantic.

He was glad that Captain de Havilland had told them thus publicly that the " square cube " law about structure weight was true; it really was, although a good many people still seem loath to believe it.

One reason for the popularity of the low wing monoplane, in the case of comparatively small aeroplanes, was that it was much more comfortable to fall over a wing spar than to bang one's head on it; but if an aeroplane were large enough this point did not arise, and then one rather favoured the high wing monoplane as slightly more efficient aerodynamically, and very much nicer for the passengers' view.

With regard to the curves appended to the lecture, these were of great interest and engineering value, but he hoped that when the lecture was finally published some information would be added as to how these curves had been evolved. If they were derived by aerodynamical calculation, might some indication be given of the form of such calculations? Or were they arrived at by spotting empirically determined results, obtained from performance figures, and running mean curves through the spots?

Major MAYO (*Fellow*): He was afraid he could not usefully contribute to the discussion, because he had not really studied the paper beforehand, and it was a paper which required careful study. He wished, however, to say a word or two about Captain de Havilland himself. He most cordially endorsed what the President had already said, and what had been said also by Major Green. He regarded Captain de Havilland as the " grand old man " of British aviation, and he was sure when he said that that he would not be misunderstood. They

knew that Captain de Havilland was one of the youngest of them all; but in experience and achievement he was a veteran. He was showing at the present time—in fact he had always shown—a magnificent example to aircraft designers by always flying his own products. They still saw him doing this; each new type he brought out he tested himself, and he was quite sure that in another twenty or thirty years' time Captain de Havilland would not only be producing world beaters in the way of performance, but flying them himself and still winning King's Cup races!

He would not attempt to discuss the lecture, but he did wish to say that he thought Captain de Havilland had made out a good case. There were, of course, one or two points on which the argument might be a little further elaborated, such points as the one Major Green had mentioned, that the cost of petrol was not the only item of cost which mattered. There were many other items of cost, for example, the cost of flying personnel and ground personnel, and with high speed aircraft with small load it was necessary to increase the number of the flying crew. But there was also the practical point that one could not always fit in the time schedules so as to do the same amount of ton mileage on the high-speed small load carrier as on the lower-speed large-load carrier. He only mentioned that point from the operator's point of view, because it was, in fact, a very important one. The operations had to be regulated according to the stages and the convenience of the services.

In conclusion, there was just one question he would ask Mr. Walker to explain a little more fully, namely, the reference to Fig. 2. Captain de Havilland had said in reference to that curve that span was used as a measure of frontal area. The speaker had not quite followed, however, what the intention there was, and he wanted it explained a little more fully. It seemed to him that span was not normally a fair measure of frontal area, and that the characteristics of the aircraft, such as whether it was a specially designed high speed aircraft with small capacity, would be an important factor determining the relative frontal area. If it were a large load carrier one would expect it to have a relatively larger frontal area.

Mr. F. M. THOMAS (*Associate Fellow*): He would not attempt a general discussion of the lecture but would only state a few facts which he believed differed from what had been said already. In 1929 an S.A.E. paper by F. W. Caldwell on variable pitch airscrews showed pretty definitely that in most cases a fixed pitch airscrew stalled at low air speed, sometimes even at blade angles as low as 8 or 10 degrees.

The cruising efficiency shown in Fig. 7 was less for the variable pitch than for the fixed pitch. He would guess that the reason was that a compromise variable pitch airscrew was chosen so as to give an extraordinarily high static thrust and take-off. It was evident that the normal fixed pitch airscrew must be compromised more heavily than the normal variable pitch airscrew in the direction of take-off, in order to get a given machine off the ground within a reasonable distance. In the usual case, therefore, the variable pitch airscrew would be chosen to give a higher cruising efficiency than the fixed pitch airscrew.

In Fig. 8 the fixed pitch static thrust was shown as a horizontal line and the variable pitch as having a thrust decreasing with increasing airspeed. It had actually been found that the slope of that curve between the static and the air-borne conditions might be either up or down, depending upon the inter-relation of the variables involved.

He commented upon the weight of the variable pitch propeller. Of course, they knew it was heavy; the question was how to get the weight down. One way of approaching the problem was by the use of wooden blades. There were various other ways, into which he could not enter at the moment. Even, however, with the present high weight, the variable pitch propeller did not necessitate

a sacrifice of a passenger, because one could get off with a higher load and really take more passengers.

Mr. F. DUNCANSON (*Associate Fellow*): They were getting rather impressed by the fact that economy in aircraft transport was improving all the time, *i.e.*, they were not only getting ten miles per gallon, but ten miles per gallon at higher speeds. The chief reason was improvement in aerodynamic efficiency. If they compared the type of machine that was designed four or five years ago, which was described by Mr. Evans as " a forest of struts " and took a look round and had a good view of the " Comet," they were impressed straight away with one good reason why flying was becoming more economical and more advantageous to everyone who used it.

Mr. F. RADCLIFFE (*Associate Fellow*): He desired to endorse one or two remarks made by Mr. Norman in connection with ground organisation, which was so sadly behind the times in this country. He thought it did need emphasis through the Press and elsewhere that better ground organisation must be provided. The motor car industry was often drawn upon as an analogy for the solution of aircraft problems, and here there was a good example, for just as the roads had enabled the motor to become really a practical proposition in this country, so something on the same lines must be done with aviation. Until there were aerodromes all over the country aviation was not going to find its true and fullest development. The benefit to be derived from air travel obviously vanished if a journey of an hour or a couple of hours by bus or other ground transport was necessary to get to or from the aerodrome.

In connection with the present lecture, he hoped the lecturer would further amplify the remarks he had made on supercharging. He had stated the facts, but the reason why so small a benefit was to be obtained would be extremely interesting to the reader.

With regard to take-off and landing regulations, he wished to add his endorsement to the facts brought out by the lecturer, and to suggest that this matter really should be taken up by the civil aviation department in reference to take-off.

The case for having long aerodromes was rather weak, inasmuch as they did not want to operate their aeroplanes in specially prepared aerodromes only; they must have the ability to take off in restricted aerodromes as well.

Great emphasis had been laid in the lecture on the view from the windows—he thought too much emphasis, when it was realised that civil flying in the very near future would consist chiefly of flying at 13,000ft., at which height the view did not matter as much as when flying at 1,000 to 4,000ft.

With regard to what the lecturer had had to say about the evolution of commercial aeroplanes and the break away from the military, he thought the passage contained a very unfair criticism. A whole lecture could be devoted to that subject, and a case could be made which would bring out the military machine just as well as the civil machine. What the lecturer had said was rather begging the question.

He wished to support the request of one of the previous speakers that the figures in the appendix should be amplified—for example, could the term " equivalent monoplane span " be amplified and a definition given? It would add very largely to the usefulness of the appendix.

Mr. J. L. HODGSON (*Associate Fellow*): He asked why, in the case of commercial aircraft, the difficulty of the variable pitch propeller should not be got over by special methods of launching. In the Navy they had catapulting.

During the 1914-18 war, rocket launching had been shown to be practicable. Why should not aerodromes on frequently used routes be equipped with catapult launching machines which could be rotated to face the wind? And why should not rocket launching be developed for the less frequently used routes?

Reply to Discussion

Mr. C. C. Walker, who was asked to reply to questions on the diagrams appearing with the lecture, said that Mr. Watts in his very clear and illuminating remarks had referred to the horizontality of the thrust curve of the fixed pitch propeller in Fig. 8. He thought he had been answered by Mr. Thomas. In fact, the only reply was that that was the way it came out based on full-scale wind channel tests made by the N.A.C.A., but the figures would be checked to ensure that they were really accurate, and it would be interesting to know if anybody felt able to state that it was impossible for a fixed pitch propeller gradually to unstall itself in going from nothing up to 100 miles per hour, thus producing the phenomenon in question.

Captain Barnwell wanted to know how the curves were derived. The curves relating to variable pitch propellers are derived from the full-scale test results of the N.A.C.A. The derivation of the other diagrams will be evident from the paper. They are in the main designer's calculations. These must, of course, be soundly based and checked from examples.

Major Mayo had asked about the span as a sort of measuring stick of the frontal area. The area of the front elevation of a machine was generally quite closely associated with the span. It usually happened that the body formed some sort of relation to the span, or at least did not depart very far from an average relationship. All the things one saw in front elevation were faired off as much as possible. If all were faired off equally well the span would be a very good measure of the resistance in the cruising condition. That was because differences in the " induced " part of the total drag when cruising between different aeroplanes which had satisfied the same take-off requirement were of minor importance.

The President (Lieut.-Colonel Moore-Brabazon): In some of the cheaper papers they were accustomed to see a little section headed " Things People Say." Some of them were very fatuous, but occasionally they had sense—he himself was quoted the other day! He would like in such a category these words to be included and to be read up and down the country:—

" It will be found, however, that no advantage in reducing costs is disclosed by low speeds and large paying loads."

He was not prepared to say that that was gospel truth, but it came from a very high authority, and if there were people who were going to dispute it and debate it, then let the debate continue at the annual general meeting of Imperial Airways, when Sir Eric Geddes and Captain de Havilland could have it out.

He was sorry that Captain de Havilland did not mention anything about Diesel engines while he was on the question of economy, because that very afternoon (Budget day) there had been a tax of 8d. per gallon placed on Diesel oil, though it was comforting to reflect that only the 8d. per gallon on petrol still had to be paid for aeroplanes; the 8d. tax on Diesel oil need not be paid by aeroplanes—about the first concession to aviation they had had in a Budget.

Those whom he was addressing were all very scientific people, and they approached the subject of aeroplanes and flying from a highly specialised point of view. Either they were very fine fliers, or they knew so much about it that they never went up! There were always extreme views expressed, and consequently he welcomed Captain de Havilland's dictum that the passenger was the ultimate user, and that it was essential that his point of view should be kept in mind throughout the design of a machine. Those were very wise words, but apart from the desirability of comfortable cushions and whether the passenger could see the ground or not, there was one outstanding disadvantage about flying, and that was the bumps. Let them not forget that they had now strained the heart of the Lord Privy Seal. There were many ways of straining the heart, but he could imagine nothing more distressing than straining it in trying to be

ill in an aeroplane. In a recent lecture before the Society a case was made out, in scientific language, for very high loading from the point of view of the passenger, and it was stated that that meant less violent bumps. That was what he would like to hear about, for he knew something himself about air sickness and it was a very real and dreadful malady.

The subject of the evening was a very large one. It included at least ten subjects on which many of them would like to dispute. But it all showed that it was much too long since Captain de Havilland gave his previous paper, namely, twelve years. He hoped that he would give another in the near future. This was not a frightening audience, and he was a master of his subject. In the meantime he proposed a hearty vote of thanks to him for his lecture.

The vote of thanks was duly accorded, and the meeting terminated.

Written Reply by Captain de Havilland

Major Green had raised the point of high landing speeds. The speaker felt very strongly that high landing speeds were permissible; in the past they had been rather afraid of them. To take some examples, the " Comet " had a loading of 26lbs. per sq. foot and the many pilots who had now flown it were rather surprised at the relative ease with which it could be landed in a fairly short space. The D.H. 86 and 89 would have been considered to have very high loadings only a short time ago, but no pilot seemed to have any difficulty in landing. As loadings got higher various forms of air brake and so forth must be used, but with these, apparently, loadings could go up a lot higher than at present.

Major Green points out that throttling the " Comet " would increase its ton mileage performance.

The point made in the paper was that within reasonable limits it was possible to design a faster machine lifting a smaller load or a slower machine with a larger load, and that broadly speaking the same ton-mileage per gallon (or per h.p.) would be obtained in either case.

That any given aeroplane will show an improvement in ton mileage if somewhat throttled is not related to the question of designing for higher or lower speeds, but to the method of operating any one aeroplane.

Mr. Evans had criticised the remarks on subsidised flying and American design. The speaker was in full agreement with Mr. Evans in his admiration of American progress and thought that this had been expressed in the paper. In discussing superiority or otherwise of American design as compared with British, it would be better to hear comparisons of speed, comfort, ton miles and so on, rather than that these qualities should be indirectly assessed in the terms of struts and wires, gleaming projectiles, bird-cagery, etc. In a similar way the materials of construction should be technically appraised. It should not be considered a virtue to use a certain material for no other reason than that it is that material. There are problems of cost, maintenance, reliability, etc.

Probably a greater proportion of British civil flying is wholly unsubsidised and unassisted than in any other country. Designers therefore have to pay greater attention here to the possibilities of unassisted use. It would have been impossible for British designers to have produced fast and initially costly aeroplanes up till quite recently with any hope of selling them. This is perhaps a better way of putting the sentence which Mr. Evans has criticised.

Major Norman had stressed the necessity for better aerodromes. The speaker was in full agreement. It was no use having one good aerodrome on an air route; there should be some sort of standard of size, taking altitude into consideration, and possibly 1,000 or 1,200 yards of concrete runway. This was really only suggesting that about four miles of arterial roadway be laid down on the aerodrome and set out, of course, in the right arrangement.

To give an example, it would appear that doubling the take-off distance

approximately doubles the pay load. Therefore by modifying a regulation and having suitable runways you can add enormously to the paying capabilities of an aeroplane. With a modern high speed machine the ceiling would still be ample for all normal requirements.

Dr. Watts had suggested that controllable pitch airscrews were not always needed; little advantage was gained unless the speed of the aircraft was high. It was found that on the "Dragon Six," which did 160 m.p.h., the convenient limit was being reached with fixed pitch propellers. Besides the advantage of an efficient pitch for take-off the controllable pitch airscrew gave the ability to use full cruising power at heights while maintaining the required r.p.m.

Captain Barnwell had also criticised certain characteristics of the controllable pitch propeller. The answer to Dr. Watts covered most of the points raised.

Regarding the basis of the curves shown in the paper, this should be fairly clear from the paper itself. They are derived from calculations, but any constants used are checked from actual results.

Major Mayo had suggested that there were more costs involved in the use of high speed machines. That was obviously correct, and one was keen that operators should put forward their view about increased speed if ton mileage was kept the same. The importance of using span as a measure resides in the fact that it determines the load which can be lifted with a given power. The load has first to be lifted and then transported. If the speed is referred to the span and power it forms a criterion of the commercial value of speed. The large load carrier with a large frontal area must (in order to take off) have a large span. The span is in practice quite a good measure of the frontal area, although it is obviously possible to make freakish departures in this respect.

Mr. Radcliffe had mentioned ground organisation and aerodromes. The speaker agreed with what he had said.

The matter of supercharging was gone into very carefully when the "Comet" was designed and it really came to this: unless one could get ground boost to take off a bigger load, supercharging did not pay if a long range was required. If one had the same take-off power and then supercharged at a height, more petrol was used and therefore the range would be less.

The case for large aerodromes was mentioned in the answer to Major Norman.

The "equivalent monoplane span" is intended to give the monoplane span having the same induced drag as a biplane under consideration. In ordinary biplanes it is equal to the span of the one (or larger) wing plus one-eighth the span of the other—the exact fraction depending on the gap.

He could not agree with Mr. Radcliffe's remark that passengers' windows were unimportant when flying at about 10,000 feet. When flying abroad at that height and even higher, owing to the far better visibility, the landscape could be of the greatest possible interest.

Mr. Hodgson had suggested that launching might overcome the necessity of the controllable pitch airscrew; would it not be a great expense to have to instal launching devices? The controllable pitch airscrew would probably become a normal part of every aeroplane in the near future. Apart from take-off and cruising advantages it made matters easier on a multi-engine machine when flying with an engine dead.

Mr. Thomas raised several interesting points about C.P. propellers. It has been the practice in this country to design the fixed pitch propeller for maximum efficiency at speed (*i.e.*, maximum or cruising). There is, therefore, no other propeller which can equal it in this respect. The take-off has to look after itself and is very bad with high speed machines.

The variable pitch is generally designed as a compromise in which a little efficiency is lost at speed (owing to big diameter) and much is gained at take off. This was what Fig. 7 was intended to illustrate.

ABSTRACTS OF PATENT SPECIFICATIONS

(Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.)

Abstracts of Patent Specifications received by the Society are published in the Journal. It should be noted that these abstracts are specially compiled by Mr. W. O. Manning, F.R.Ae.S., for the Journal and are only of those actually received and subsequently bound in volume form for reference in the library. These volumes extend from the earliest aeronautical patents to date, and form a unique collection of the efforts which have been made to conquer the air.

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Aeroplanes—Construction

428,896. *Improvements in or relating to Wind or Like Screens for the Cockpits of Aircraft, Motor Boats, or Motor Cycle Sidecars, or for Use in Similar Situations.* The Fairey Aviation Co., Ltd., Cranford, Hayes, Middlesex, and Tips, E. O., 434, Chausée de Bruxelles, Jurnet Gosselies, Belgium. Dated 13th June, 1934. No. 17,499.

This specification describes a windscreen for a two-seater aircraft in which the double cockpit may be normally completely protected, while provision is made for easy entry into the cockpit, and also for extended protection for the rear occupant when standing up. It consists of a front fixed portion of normal form, followed by a portion which is hinged laterally to allow ease of entrance. This is followed by a rear portion which is hinged in such a way that while, normally, it protects the rear of the cockpit, the rear portion of the screen may be raised allowing the front of the rear portion to telescope into the rest. The screen, when raised, is stated to give adequate protection to the rear gunner.

429,311. *Improvements in or relating to Wing Structures for Aircraft.* Duncanson, F., Seaplane Base, Brough, East Yorkshire. Dated April 3rd, 1934. No. 10,018.

It is stated that numerous aeroplane accidents have occurred owing to the pilot flattening out too suddenly from a steep dive and causing the wings of the machine to break away from the body. It is proposed, therefore, to use a spar or spars in the wings in which there is a weaker spot about half-way between the wing root and the inner end of the aileron. It is suggested that under these circumstances failure would only cause an increase of dihedral and would leave the pilot still in control. It is suggested that if the spar factor was 6.4, a factor of 6.2 would be suitable for the weak spot, and it is stated that the device is particularly suitable for monospar wings with tubular reinforced spars.

431,089. *Improvements in or relating to Wing Structures for Aircraft.* Duncanson, F., Seaplane Base, Brough, Yorks. Dated April 3rd, 1934. No. 10,017/34.

In the case of single spars of the tubular type used for aircraft wings, it has been found desirable to strengthen these members by other means than by adding corrugated sheet metal to the upper and lower surfaces. It is therefore proposed to use, in addition, four tubular booms, fitted as it were one on each corner of a square containing the tubular spar and connected to the spar itself by sheet metal disposed lengthways to the spar and welded both to the spar and to the booms.

430,759. *Improvements in or relating to Metal Beams.* Petters, Ltd., and Bruce, R. A., both of Westland Works, Yeovil, Somerset, and A.T.S. Co., Ltd., of 314, Clement's Inn, Strand, London, W.C.2. Dated Dec. 22nd, 1933. No. 36,099.

It is proposed to construct metal spars for aircraft with polygonal booms and corrugated webs, the lips of the polygonal booms being separated so that the corrugated web may be introduced between them and riveted thereto. The shaping of the spar towards the wing tip is arranged by riveting to both sides of the web, both top and bottom metal sheet rolled to a substantially L section which can be fitted insde the ends of the booms. The spar may be strengthened when required by introducing and bolting tubes into the booms or by means of angle pieces, plugs, etc.

429,186. *Improvements in or connected with Biplane Wing Systems for Aircraft.* Vickers (Aviation), Ltd., and Wallis, B. N., both of Weybridge Works, Byfleet Road, Weybridge, Surrey. Dated Nov. 25th, 1933. No. 33,005.

This specification describes a method of constructing biplane wings in which the spars are stated to be relieved of bending and torsional stresses by means of the provision of stress units which are held apart by spar sections, which are held against lift forces by diagonal interplane connections, which are stayed against drag and diagonal drag members and which are held against torsion stresses by interplane struts. The construction described shows a biplane of normal form having interplane struts arranged as in a Warren truss. The wing carries a number of stringers from root to tip which are connected by Warren bracing. A rib occurs at each interplane strut position and the single wing spar is tubular. Drag bracing is carried diagonally between the ribs both to the leading edge and trailing edge. The interplane struts are of lattice construction and are bolted rigidly to the plane members.

429,188. *A New or Improved Method and Means for Assembling and Connecting Intersecting Bracing Members.* Vickers (Aviation), Ltd., and Wallis, B. N., both of Weybridge Works, Byfleet Road, Weybridge, Surrey. Dated Nov. 27th, 1933. No. 33,113.

This specification refers to a method of constructing an aeroplane wing in which the structure consists of a number of intersecting spars arranged in the manner of a trellis. These spars are so shaped that when the wing is covered the desired wing contour is obtained. The joint between the spar sections consists of a hollow tubular member having a flange at each end to which the flanges of the spars are riveted. The spar web can also be bent partially round and be riveted to the tubular member. Detailed information is given about the manner of assembling such wings.

431,767. *Airplane Wings.* L.P.R. Co., 277, Park Avenue, City and State of New York, U.S.A. Dated Oct. 11th, 1933. No. 28,103. Specification not accepted.

It is proposed to place a small aerofoil of high aspect ratio well in front of and above the main plane itself. This aerofoil is connected by means of, say, a rod and crank connection, with a flap of normal type at the rear of the main plane itself. When these are operated together many advantages are claimed for the combination, such as increased lift at large angles and reduced drag.

431,895. *Improvements in or connected with the Construction of Cantilever Wings and other Aircraft Structures.* Short Bros., Ltd., and Gouge, A., both of Seaplane Works, Rochester, Kent. Dated July 28th, 1934. No. 22,090.

It is proposed to construct metal aircraft spars of four booms which are connected together by horizontal and vertical diagonal bracing members formed of tubes. The booms are of cruciform section of extruded duralumin and the bracing members are connected to the flats of the boom cruciform section by means, preferably, of gusset plates. One leg of the cruciform section may be longer than the others in order to facilitate this. The cruciform section may be tapered in section by means of milling off superfluous metal and an internal bracing of wire may be arranged by drilling holes diagonally through the section of the cruciform boom to take, say, eyebolts.

431,595. *Improvements in or relating to Wing Structures for Aircraft.* Duncanson, F., Seaplane Base, Brough, E. Yorks. Dated April 3rd, 1934. No. 10,019.

In connection with aircraft wings constructed with single spars of tubular type, the spar is stiffened on the upper and lower surfaces with corrugated metal which may not cover the same area in each case, so that the neutral axis is not necessarily in the centre of the spar. The spar is constructed in two longitudinal sections which are riveted together by outwardly turned flanges; the joints need not necessarily be in the centre line of the spar. Instructions are given for assembling a spar so constructed with information about rib connections, etc.

Aircraft—General

429,948. *Improvements in Aeroplanes.* Boulton and Paul, Ltd., Riverside Works, Norwich, and North, J. D., Hill House, Eaton, Norwich. Dated Dec. 11th, 1933. No. 34,787.

This specification describes a compound aircraft in which the upper member is the lifting portion, termed the auxiliary aircraft, while the lower member, termed the main aircraft, is the machine which is to be launched with the assistance of the auxiliary member. As the upper member is lightly loaded and the lower member is heavily loaded, when they are together it is stated that there is lift force transmitted from the upper to the lower, and it is claimed therefore that this arrangement facilitates separation, as, on this occurring, the upper member will rise and the lower member will accelerate. Various claims are made in connection with the type of engines and propellers to be used and in connection with the method of control in flight.

430,068. *Improvements in Aeroplanes.* Boulton and Paul, Ltd., Riverside Works, Norwich, and North, J. D., Hill House, Eaton, Norwich. Dated Dec. 11th, 1933. No. 28,033.

In the case of compound aircraft it is preferred that the auxiliary aircraft should be above and the main aircraft below. It is proposed to construct the

auxiliary aircraft with a normal tail and the main aircraft with a tail supported with twin side by side fuselages or outriggers in order to allow the twin aircraft greater freedom to change fore and aft trim at the moment of release. Connections between the two are made from the bottom of the landing gear of the upper aircraft, on the wings of the lower aircraft, and by a releasable link located centrally and midway between the wings and tail.

430,071. *Improvements in Aeroplanes.* Boulton and Paul, Ltd., Riverside Works, Norwich, and North, J. D., Hill House, Eaton, Norwich. Dated Dec. 11th, 1933. No. 33,023.

In the case of compound aircraft it is proposed to assist the pilot to select the right moment for separation by providing at each point of attachment a pressure measuring device with indicators placed in view of the pilot, so that he could ascertain whether forces existed so that release of attachment would result in separation. It is pointed out that large compression forces at the rear connection would suggest the possibility of the tails contacting on separation and that if such a force existed the pilot would delay release. Means are described for preventing release until suitable conditions exist. Details are given of various suitable pressure measuring contrivances.

Autogiros

428,231. *Improvements in or relating to Rotative Wing Aircraft.* Coats, A. G., Gloucester House, Park Lane, London, and Hafner, R., Monthergasse 47, Vienna 13, Austria. Dated Nov. 9th, 1933. No. 31,300.

In the case of rotative wing or autogiro aircraft it is proposed to use rotor blades which are loaded or are arranged to have their centre of mass towards the tip in order to give them a large radius of gyration. The blade section should have a good L/D ratio and low resistance at small incidences. It should also have a section which permits a small movement only of the centre of pressure such as a symmetrical section. It is proposed to provide means enabling the incidence of the blades to be altered and also means by which the engine drive can be clutched or de-clutched. In this way it is stated it is possible to arrange for such an aircraft to take off and land vertically, without appreciable lateral motion.

Bombs and Ballistics

429,061. *Gun Mountings on Aircraft.* Sir W. G. Armstrong, Whitworth Aircraft, Ltd., and Lloyd, J., both of the Company's Works, Whitley, near Coventry, Warwickshire. Dated July 7th, 1933. No. 19,297.

It is proposed to protect the gunner in a service aircraft by enclosing him in a spherical shell covered with, preferably, bullet-proof glass. This shell is mounted on a vertical pivot and is provided with a vertical slot through which the gun can be fired. The shell rotates round its vertical pivot and the rotation is controlled, preferably, by an electric motor geared to the shell. This electric motor is energised by electric switches placed on each side of the gun slot and actuated by the pressure of the gun itself against them, so that if the gunner is trying to train his gun on an object the shell automatically rotates until the object comes on the sights. An internal shell revolving inside the other may be used in a similar manner for providing elevation automatically. These shells may be used together or independently.

431,550. *Improvements connected with Gun Turrets for Aircraft.* Short Bros., Ltd., and Parker, H. G., both of Seaplane Works, Rochester, Kent. Dated Dec. 1st, 1934.

It is proposed to place the gun turret at and above the after end of the fuselage or hull of an aircraft, the gunner firing forward; an extensive field of

fire is claimed for this position. The drawing shows a flying boat having the guns mounted in a body above the tail end of the hull out of which the fin and rudder project.

432,134. *Improved Form of Rapidly Removable Cover for Gun Turrets.* Boulton and Paul, Ltd., Riverside Works, Norwich, Norfolk, North, J. D., Hill House, Eaton, Norwich, Norfolk, Hughes, M. A., Westfield, Plumstead Road, Norwich, Norfolk, and Doe, A., St. Peters, Earlham Green Lane, Norwich, Norfolk. Dated Feb. 15th, 1934.

In the case of rotatable gun turrets for aircraft, it is proposed to provide a removable top so as to allow the gunner to escape in case of emergency. The gun turret is circular in section with rounded ends and is framed with hoops and upright members. It has a slot for the gun barrel. The removable top is framed in a similar manner and is connected to the main turret by a number of vertical dowel pins so that it can be pushed off when required. A locking device consisting of another dowel, secured by an easily removable split pin, is also described.

Control of Aircraft

427,422. *Improvements in or relating to Gyroscopic Apparatus for Example, for Air and Other Craft.* Brown, J. P., Waldron Eyot Hotel, South Croydon, Surrey. Dated Oct. 24th, 1933, No. 29,473; and Nov. 7th, 1933, No. 30,904.

Specification 341,519 is referred to and it is stated that in such apparatus when the spindle shifts angularly so that its axis no longer coincides with that of the rotor, a small component of the friction produces a couple tending to cause precession of the gyro rotor into realignment with the spindle. Thus, if the spindle changes its orientation in space the rotor will tend to follow it and thus also change its orientation in space. In order to avoid this, means are provided for imparting to the spindle a follow-up movement relatively to the craft so that the moment the rotor axis shifts relatively to the craft the spindle is given a corresponding movement to bring it back into alignment with the rotor. So the present invention comprises, in gyroscopic apparatus, the combination with gyroscopic mechanism of the type specified, of servo means actuated by the movement of the rotor axis relative to the spindle about an axis of control at right angles to the spindle axis, and serving to impart to the spindle a follow up movement relatively to its support about that axis of control to bring the spindle axis again into a plane containing the rotor axis and the said axis of control.

430,941. *Improvements in or connected with Aircraft.* Boulton and Paul, Ltd., Riverside Works, Norwich, Norfolk, and North, J. D., Hill House, Eaton, Norwich, Norfolk. Dated June 8th, 1934. No. 17,028.

The scheme described is the operation of a wing flap by means of a bellows placed between it and the plane, the opening and closing of the flap being assisted by varying the air pressure within the bellows. This main flap is connected to a small auxiliary flap also placed on the underside of the wing, but opening forward. This flap collects high pressure air when open, and this air is conducted into the bellows and assists in the opening of the main flap. In order to close the latter a passage is opened from the bellows to a low pressure region above the plane. The valves and flap gears are connected by a link gear so that they operate appropriately according to the movement of the control by the pilot.

431,071. *Improvements in or relating to Control Levers for Aircraft, or Similar Rocking Lever Devices in Control Mechanisms.* Coats, A. G., Gloucester House, Park Lane, London, W.1, and Hafner, R., Mantlergasse 47, Vienna, 13, Austria. Dated Jan. 1st, 1934. No. 38.

In the event of an aircraft flying under such conditions as to impose a permanent load on the control stick, it is proposed to relieve this load by the following construction. The stick is provided with two segments of a sphere which are engaged with fixed annular spherically-shaped bearing rings, which are mounted so that the amount of friction may be adjusted. It is stated that this construction sets up a strong wedging action which will hold the stick against reverse action.

Engines

427,342. *Cowling for Aircraft Engines.* Armstrong Siddeley Motors, Ltd., and Reynolds, R., both of Armstrong Siddeley Works, Park Side, Coventry, Warwickshire. Dated Dec. 13th, 1933. No. 35,053.

It is stated that in the case of cowling of the type now used for radial air-cooled engines in aircraft there is a tendency for the engine to be overcooled at high speed if the cooling is adequate for climbing conditions. It is proposed, therefore, to fit in front of the cowling a fixed saucer-shaped member which has openings in it of trapezium form arranged opposite the cylinders or cylinder blocks of the engine. Arrangements are made for these openings to be opened or partially closed, etc., at the desire of the pilot.

429,542. *Improvements in Radiators or Condensers for Evaporative Cooling Systems of Aircraft Engines.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Williams, L. H., Hillside, Swakeley's Road, Ickenham, Middlesex, and Lyon, G., Ranmoor, Fulmer Road, Gerrards Cross, Bucks. Dated April 19th, 1934. No. 11,825.

In the case of surface radiators for aircraft the radiators extending over the upper and lower surfaces of the wings it is proposed to join the upper and lower surface with some circular fins in the interior of the wing for the purpose of increasing the surface. Air is allowed to pass through the fins and through the interior of the wing, its entrance being controlled by manually operated ports. Alternatively, the fins may be replaced by corrugated tubular connections between the upper and lower portions of the surface radiator, through which air is permitted to flow in the same manner.

430,002. *Improvements in and relating to Power Transmission Couplings.* Strandgren, C. B., 14 rue Galliani, Versailles, France.

The specification describes a type of coupling between two shafts which each carry a disc, which discs are opposite to each other. One disc carries two chain wheels connected by a chain, and the chain wheels have slots which are engaged by pins attached to the other disc. A gear wheel may be substituted for the chain. Various modifications are described, including arrangements in which there are more than two chain wheels connected by chains.

430,905. *A New Method and Means for Reducing the Resistance of Air-Cooled Engines and Like Obstructions on Aircraft.* Thurston, A. P., Bank Chambers, 329, High Holborn, London, W.C.1.

In order to reduce the resistance in flight of air-cooled aircraft engines it is proposed to smooth out the airflow by means of small members called riders, which are of aerofoil shape in cross section and which are of accurate shape in end view. These occupy approximately the position of a Townend ring, but

are shaped in such a way that they rotate round the engine centre automatically when the machine is in flight. It is claimed that the effect is to produce a smoothing effect on the airflow with a consequent reduction of resistance.

Helicopters

432,124. *Improvements in Aircraft of the Helicopter Type.* Asboth, O., 1, Gower Street, London, W.C.1. Dated Oct. 18th, 1933. No. 28,864.

In the case of lifting rotors it is proposed to form the inner portion of the blade with a section of low incidence so as to produce an autogyration effect while the outer portion of the blade has an incidence lessening from the inner portion to the wing tip. The machine has two three-bladed rotors with blades of this type rotating about the same axis, which can be driven in opposite directions by the motor. Alternatively, the autogyratory portion of the blade may be increased in effect by using additional shorter blades which may be de-clutched when motor power is being used. Automatic controls of the compressed air or hydraulic type are referred to.

Instruments

429,319. *Improvements in Optical Devices for the Control of Flight.* Nistri, W., 11, via Francesco Negri, Rome, Italy. Convention date (Italy), July 21st, 1933.

It is proposed to fit a special panel in place of the usual instrument board in aircraft, on to which the indications of the various instruments are projected by an optical system, light being obtained from an electric lamp. The optical system appertaining to the compass contains a Wollaston prism controllable by the pilot which produces a rotation of twice the angular amplitude in the image of the system of needles. It is stated that the instruments required for this arrangement may be much smaller than usual and that they may also be much simpler as no amplifying mechanism is required. It is also claimed that the images of the indications of the instruments which correspond to the predetermined conditions of flight can be arranged so that when these conditions are satisfied the images assume a simple geometrical arrangement relatively to one another.

Miscellaneous

428,716. *Improvements in and relating to Ground Apparatus for Facilitating the Landing of Aircraft.* Low, A. M., 1, Woodstock Road, London, W.4. Dated Feb. 19th, 1934. No. 5,352.

It is proposed to place a system of coils under a landing deck for aircraft, which coils are to be fed with alternating current so that the coils will generate eddy currents in aircraft approaching so as to cushion the descent of the aircraft. It is also proposed to arrange the coils so that they are under the control of the pilot of the aeroplane by means of a remote control apparatus so that an aeroplane descending with one wing dipped may be righted by an appropriate energisation of the coils.

431,551. *Improvements in Stabilising and Damping Devices.* Fabry, J., 218 rue de Rivoli, Paris, France. Convention date (France), Dec. 1st, 1933.

In the case of aerial bombs, torpedoes, or other similar objects, it is proposed to improve their fore and aft stability in motion by means of an improved method of finning. The fins proposed are thicker towards their extremities than next to the body, and have flat inclined leading edges and flat tops. This particular shape is said to confer the stability claimed.

431,442. *Improved Reciprocating Blade Propeller or Impeller, Particularly for Use on Ships, Airplanes and Pumps and Compressors and Like Apparatus.* Le Clezio, L., Andeville (Oise), Paris, France. Convention dates (France), Nov. 3rd, 1933, and Oct. 6th, 1934.

The propeller described consists of a reciprocating element operating in a tube arranged so as to act like a piston on the outward stroke and to fold on the return so as to permit the water to flow by. It consists of a number of blades up to eight folding backwards from the centre, and it is claimed that the arrangement may be used for sustaining or propelling aircraft, although it is apparently normally intended for ship propulsion.

431,067. *Improvements in and relating to Aircraft.* The Supermarine Aviation Works (Vickers), Ltd., and Black, A., both of the Company's Works, Woolston, Southampton, Hants. Dated Dec. 30th, 1933. No. 36,698.

In order to prevent the passengers or the crew of aircraft from slipping on those portions of an aircraft on which they are obliged to walk on entering or leaving, it is proposed to spray such portions with metal, it being stated that the roughness so produced is sufficient.

430,802. *An Improved Device for Removing Ice from Structures such as Aeroplane Wings Exposed to Ice-forming Conditions.* United Air Lines, Inc., 221, North La Salle Street, Chicago, Illinois, U.S.A. Convention date (U.S.A.), Nov. 28th, 1933.

In order to remove ice from the leading edges of aircraft wings it is proposed to cover the front part of the wing with a flexible curtain fitting close to the nose and extending some way over the upper and lower surface. This curtain is adapted to be drawn backwards and forwards over the leading edge by means of, say, an electric motor, thereby bending the curtain and breaking the ice off the surface.

Model Aircraft

428,053. *Improvements in or relating to Toy Aeroplanes.* Hermann Auge, Krelingstrasse 35, Nuremberg, Germany. Dated Oct. 7th, 1933. No. 27,703.

The toy aeroplane described is of normal form and has a cylindrical metal body, the propeller being driven through gearing from a torsionally acting helically coiled metal spring. The plane is located on the body by hooks engaging with holes in the body and is kept in place by an elastic band. The undercarriage has curved resilient members which are pivoted on the body.

Parachutes

428,389. *Improvements in or relating to Parachutes.* Muller, M., Waterloo Ufer 14, Berlin, S.W.61, Germany. Dated Nov. 13th, 1933. No. 31,602.

In order to avoid severe shocks to the human body when a parachute of the normal type opens rapidly at high speed, it is proposed to provide a small parachute between the main parachute and the man. This small parachute is arranged to open first with the aid of springs and its resistance slows down the velocity of the system before the opening of the main parachute. A small additional parachute may also be added making three in all. Full details of packing arrangements are described.

430,793. *Improvements in or connected with Aircraft.* Utin, S., 54, High Street, Marylebone, London, W.1, and Arnold, F., 39, Wimpole Street, London, W.1. Dated Oct. 26th, 1934. No. 30,751.

It is proposed to fit a parachute to an aeroplane so as to enable the latter to be landed safely in emergency. The parachute is folded in a container carried on the upper part of the aeroplane, approximately over the centre of gravity. The top of the parachute carries a metal plate which normally forms the lid of the container, and there is attached to this plate a rod carrying a piston which normally fits inside a tube in the interior of the aeroplane. To operate, the pilot releases a spring which forces the piston out of the tube, and consequently, the parachute out of the container.

Piloting

429,133. *Improvements in or relating to Automatic Steering Devices.* Askania Werke Aktiengesellschaft, vormals Centralwerkstatt Dessaw und Carl Bambergfriedenau, Kaiserallee 87/88, Berlin-Friedenau, Germany. Convention date (Germany), Aug. 2nd, 1933.

It is stated that in the case of the controls of heavy aircraft in gusty weather, automatic control, as normally used, results in the aircraft swinging back too far, thereby passing the desired course line. The specification describes means by which, it is stated, this difficulty may be obviated. It is proposed to transmit the deflections of the system to the force controller through the intermediary of a damped resilient connection comprising two levers rotatable with respect to each other; said two levers being connected to one another by means of a spring coupling and also by a damping device so that upon the return of the deflection the force controller is caused to influence the control motor in the opposite direction before the value of the deflection has returned to zero. The apparatus is described in connection with a jet tube as described in British Patent Specification No. 397,805.

Pilots and Piloting

431,049. *Improvements to Optical Projection Apparatus.* Miles, G. H., Burlington, Richmond Road East, New Barnet, Herts. Dated Nov. 29th, 1933. No. 33,457.

This specification describes an apparatus for teaching motor car driving, etc., by which an indication of a road is shown on a transparent screen in front of the driver and moved in accordance with the movement of the controls. A modification of the arrangement is described for use in teaching the flying of aircraft. The route which appears on the screen is erected in dummy on a flat plate which is illuminated electrically and can be moved in accordance with the movement of the controls.

Undercarriages

428,265. *Cantilever Type of Landing Gear for Flying Machines.* Messerschmitt, W., 118a, Haunstetterstrasse, Augsburg, Germany. Convention date (Germany), Aug. 23rd, 1933.

In the case of aircraft having landing wheels carried on cantilever struts it is proposed to place a rupturing zone or fouling point at the place where the strut emerges from the fuselage or wing. The advantage claimed is that, in cases where the landing imposes loads greater than the strut is designed to bear, rupture occurs at a place which will do the minimum damage to the aircraft and will minimise the risk of turning over. The strut can be made shock-absorbing in any known way, and the load required to rupture may be different in different planes.

427,829. *Improvements in Brakes.* The Dunlop Rubber Co., Ltd., 32, Osnaburg Street, London, N.W.1, and Goodyear, E. F., Wright, T., and Trevaskis, H., all of the Company's Works, Foleshill, Coventry, Warwickshire. Dated Dec. 22nd, 1933, No. 36,083, and May 12th, 1934, No. 14,408.

The brake controlling devices are fitted on each side of the pilot's rudder bar and are worked through the toes of his boots so that either brake can be used differentially. The device used consists of a piston working in a cylinder operated by a lever, the pressure produced by the piston in the cylinders being directly transmitted to the wheel brakes. The pressure from the lever is transmitted to the pistons through a ball-headed connecting rod, the ball working in a recess in the piston itself. In order to enable the brakes to be held on when the machine is at rest an additional manually operated control is provided. This consists of a ball valve which can be put out of action by the pilot, but which can be permitted to close the return fluid path from the wheel brakes, thus preventing these from being released.

428,539. *Improvements relating to Retractable Aircraft Undercarriages.* Hawker Aircraft, Ltd., Canbury Park Road, Kingston-on-Thames, Surrey, and Camm, S., of the same address. Dated Nov. 15th, 1933. No. 31,867.

The undercarriage described has the wheel carried between two shock-absorbing struts connected to the front spar of the wing which are supported by two diagonal struts connected to the rear spar of the wing. Retraction takes place backwards, the whole undercarriage swinging on the pivot on the front spar, the rear struts being folded backwards. One system of operation described consists of a system of cords and pulleys by means of which the undercarriage is lifted and also the rear struts are unlocked from their operating position and carried backwards by means of a pulley rotating a lever carrying the end of the strut. These two operations are carried out simultaneously by means of a cord operated by the pilot which pulls on a pulley round which the retracting cord passes, thus giving a differential action. The undercarriage is returned by means of a separate cord which is arranged to swing the rear strut into position and to re-lock the gear. An alternative mechanism is described in which a bevel differential gear is used to effect the same purpose, but in this case retraction takes place by means of pinions gearing into toothed segments.

429,867. *Improvements in or relating to Landing Gear for Aeroplanes.* Societé d'Inventions Aeronautiques et Mecaniques, S.I.A.M., 1, Route des Alpes, Fribourg, Switzerland. Convention dates (France), May 24th, 1934, and June 27th, 1934.

The chassis described is of the usual type with a shock-absorbing leg attached to the front spar and a rear diagonal leg running to the rear spar. Folding is permitted by hinging the rear leg at a point along its length so that it may be swung out of the way while the rest of the chassis rotates rearwards and upwards about the front spar. Locking when extended is carried out by means of a member attached to the rear part of the diagonal, which member carried a hook which is engaged by a hydraulically controlled mechanism. In a modification described, this hook may be used for locking, whether the mechanism is extended or retracted.

429,167. *Improvements in or relating to Tail Skid Shoes for Aircraft.* Aktiengesellschaft der Eisenund Stahlwerke vormals Georg Fischer, Schaffhouse, Switzerland. Convention date (Germany), Jan. 31st, 1934.

The inventor proposes to increase the wear-resisting properties of tail skids by welding on a layer of white iron, which may be alloyed with chromium, etc., for the purpose of increasing hardness.

431,042. *Improvements relating to Tail Wheels and the Like for Aircraft.* Dowty, G. H., 17, Lansdowne Crescent, Cheltenham, Gloucestershire. Dated Jan. 31st, 1934, No. 6,233, and Feb. 16th, 1935, No. 5,088.

In the case of tail wheels for aircraft it is considered desirable that the tail wheel shall be resiliently mounted and that the wheel shall be self-centring. The construction described consists of telescopic tubes with a spiral spring for resiliency coupled with an arrangement by which two concentric members have each an angular force kept together by a spring when the load is off the tail skid. The two angular concentric spring mounted faces will tend to take up a position in which the two angular faces are together, this action providing the self-centring. It is also proposed that the resiliency shall be checked by a braking device consisting of a band brake acting between the telescopic tubes.

430,831. *Improvements relating to Landing Gear for Aircraft.* Norton, J. B., Capt., Marston Hall, Grantham, Lincolnshire. Dated Jan. 11th, 1934. No. 1,100.

This specification describes a device for the automatic landing of aircraft in which the operating element is a skid, normally folded, but which, when landing, projects downwards behind and below the chassis. On contact with the ground this skid releases a spring which operates the control column in the appropriate direction for flattening out. Damping is provided by means of a hydraulic mechanism and the amount of damping may be controlled by a centrifugal governor driven by a small fan, the damping being thus proportional to the forward speed at the time of landing.

430,842. *Aeroplane Brakes and Their Controls.* Dunlop Rubber Co., Ltd., 32, Osnaburgh Street, London, N.W.1, Goodyear, E. F., of the Company's Works, Foleshill, Coventry, Warwickshire, and Trevaskis, of the Company's Works, Fort Dunlop, Erdington, Birmingham. Dated March 14th, 1934. No. 8,037.

This specification describes a method of operating aircraft brakes in which the brakes may be applied through a lever operated by the pilot on the joystick, and operated differentially by means of a mechanism connected to the pilot's rudder bar. This mechanism consists of two diagonally placed relay mechanisms which are operated together by the lever operated by the pilot or which are operated differentially by means of a rotatable slot mechanism from the pilot's rudder bar.

Wireless

428,212. *Improvements in and relating to Direction Finding Apparatus.* The British Thomson Houston Co., Ltd., Crown House, Aldwych, London, W.C.2. Convention date (U.S.A.), Oct. 26th, 1932.

Among other objects it is proposed to provide an improved direction finder which will provide both substantially constant angular sensitivity and symmetrical angular indication. The direction finding system may comprise non-directive and rotatable directive antennæ, means for combining oscillations received by the antennæ to produce distinctive currents whenever the directive antennæ is at an angle to the null position with respect to a radio transmitter and means, including a non-linear resister having a substantially instantaneous response to the distinctive currents for producing a direct current variable in accordance with the position of the directive antennæ. Oscillations received on directional and non-directional antennæ are modulated and combined and caused to produce distinctive current which, through a substantially instantaneous responsive non-linear resister, are caused to give a direct current indication of the position of the directive antennæ.

REVIEWS

Seaplane Float and Hull Design

By Marcus Langley, M.I.Ae.E., A.M.I.N.A. Published by Sir Isaac Pitman and Sons, Ltd. Price 7/6.

This book is one of a number of short text-books on various aeronautical subjects which are intended to instil the main principles of the matter dealt with into the minds of students. The author has the advantage of having been brought up as a naval architect, of having had considerable experience in instruction, and of having been closely connected with aviation matters for some years past; it is therefore to be expected that the book would be sound.

This expectation is justified. All the matters concerning principles are well explained and illustrated by examples and the methods of making the usual calculations are clearly described. There are also chapters on tank tests and float design, while hull design for flying boats has a chapter to itself. Structural matters are not dealt with.

The book should fulfil its object admirably.

Practical Performance Prediction of Aircraft

By Lieut.-Colonel J. D. Blyth, O.B.E., A.F.R.Ae.S., M.I.Ae.E. Published by Sir Isaac Pitman and Sons, Ltd. Price 5/-.

This book is the latest addition to the Aeronautical Engineering Series, published by Pitmans, and deals solely with performance estimation for aircraft. There is nothing very novel in the methods suggested, but they are clearly explained and illustrated by examples.

In books of this type there is always a danger that the student may take formulæ as established on the authority of the author and may not trouble to enquire into the reason for the form or the method of derivation. It is quite impossible to give this sort of information in a book of this type, but every assistance should be given to the student who desires information on fundamentals by a full bibliography. Here the book is lacking, the bibliography consisting of only six books, one of which is out of date.

To those who wish to make a general estimate of the performance of aircraft the book will be useful, and it is likely that in the near future many possessing little technical knowledge will be attempting to design light aircraft; these will find the work invaluable. For serious estimates of the performance of large and important machines a good deal more is required than can be found in this book.

Aircraft Manufacture

By R. McKinnon Wood. Issued by the New Fabian Research Bureau. Price 6d.

Mr. McKinnon Wood is well known in aeronautical circles. Not only has he held a very important technical post at the R.A.E., Farnborough, but he has also been a Member of Council of the Royal Aeronautical Society. It is therefore to be expected that any opinions he may advance respecting the future of the aeronautical industry would have behind them a background of knowledge.

In politics he is a Socialist, and this book contains proposals for the nationalisation of the aircraft firms, which are, apparently, to be taken over and

run as branches of a Government Department, the technical development being undertaken by a "Corps of Aircraft Constructors," whose head would be a Director of Aircraft Construction.

The terms on which the firms are to be taken over is also explained, and it may be of interest to note that the total compensation to be paid to the four most important firms in the industry totals only some £150,000. Mr. McKinnon Wood admits that the shareholders will lose a lot of money, but appears to think that they deserve it for financing armament companies.

The compensation is based on assets only, by which term he appears to mean plant, buildings and machinery. Such items are merely the dry bones of a successful firm, essential to the structure as the skeleton is to the body, but the real source of success lies in the human element, the tradition, the personality of the executive, and the feeling of team work leading everyone to give of his best for the benefit of the whole.

This is the only part of the firm that is really worth preserving and it is the part which Mr. McKinnon Wood proposes to destroy. It is possible that a Chief Designer may be offered a job as a member of his Corps of Aircraft Constructors, but his individuality will be destroyed, and with it, the greater part of his value.

It is extraordinary to hear from the author that this Society exists merely to duplicate the duties of the Aeronautical Research Committee. His experience on the Council must have taught him that it has many other activities besides the reading and discussion of papers. Under the nationalisation scheme propounded here all these activities will presumably disappear, as the Society is to be converted into a Trade Union.

Aerodynamic Theory

Edited by William Frederick Durand. Vol. IV. Published by Julius Springer, Berlin. Price R.M. 25.

This is the fourth volume of the series of English text-books published under a grant of the Guggenheim Fund, and is the first of this admirable series to deal with practical problems, the previous volumes being concerned solely with theoretical matters.

It contains four papers only:—Applied Airfoil Theory, by A. Betz; Airplane Body Drag and Influence on Lifting System, by C. Wieselsberger; Airplane Propellers, by H. Glauert; and Influence of the Propeller on other Parts of the Airplane Structure, by C. Koning.

It is sufficient to say that both the matter and the way it is set out in this book is admirable, and that the book is one which no aircraft designer can afford to be without. He will find much that is invaluable to him in the treatment of practical problems enlightened by theory.

International Index to Aeronautical Technical Reports, 1934

Prepared by the Society of British Aircraft Constructors and published on behalf of the Society by Sir Isaac Pitman and Sons, Ltd. Price 5/-.

This book contains an index to technical reports which are arranged under headings to facilitate reference. Some 90 different journals, technical papers, reports by national research establishments, etc., are referred to. In fact references are made to every important technical resource in the world.

An index of this sort is invaluable. Everyone engaged in technical matters has experienced the difficulties in getting references which will help in the elucidation of some problem, and the S.B.A.C. has done a most important piece of work in arranging this index.

Sir Sefton Brancker

By Norman Macmillan. Published by William Heinemann, Ltd. Price 21/-.

Air Vice-Marshal Sir Sefton Brancker was a very notable figure in the aeronautical world, as Director of Civil Aviation he was the guide of civil aviation in this country during the early and most critical years of its existence, and the position that England holds in aerial transport to-day is largely due to his work.

By profession a Gunner, he was attracted by flying in the very early days, and his keen imagination enabled him to foresee, even then, many of the developments that have since happened. From the first, he realised the immense importance of the aeroplane in connection with warfare, and he lived to see most of his forecasts come true.

The first half of this book is a narrative written by Sir Sefton Brancker himself. It deals with his early life in England and India, but the most interesting part is concerned with his Great War experiences in England, when he was in charge of Military Aviation, under Lord Kitchener, and was in command of the 3rd Wing R.F.C. Later he was Director of Air Organisation at the War Office and afterwards Deputy Director General of Military Aeronautics, while later still he was appointed to the Middle East Command, R.F.C., and held this post at the fall of Jerusalem. He returned to England to take up the post of Master-General of Personnel in the Air Council, and finished his career as Director of Civil Aviation.

He was a man extremely difficult to describe to those who did not know him. A hard worker, whose heart was always in the job which had been given him to do, and which he did with painstaking care and exactness, he yet found time for social life of all types and was frequently to be found dancing in the small hours of the morning. Gifted by nature for a capacity for being awake more hours of the day than most men, he never allowed his play to interfere with his work, and his late hours did not prevent his attending his office at the usual time. He had the capacity of the leader of men to arouse the enthusiastic attachment of those who he came in contact with, and to many of these he was not only a friend but a counsellor and guide. The hero worship of one of his admirers went so far as to keep, still in an unwashed state, a shirt which had once been worn by him.

Although he was a soldier with experience of War Office administration, he always managed to avoid becoming a bureaucrat. Red tape, when it hampered something which he saw had to be done, was cut ruthlessly, and he himself describes one important instance when he gauged official approval for an action which was highly improper, by the mildness of the censure. Further, he had a charm of manner which made him welcome everywhere, combined with the storytelling skill of a born raconteur, and if he wished he could be the soul of any party he attended.

But the great passion of his [illegible] aviation and the post of Director of Civil Aviation was the ideal job for a man of his type, the roundest of round pegs in a perfectly circular hole. All of those engaged in aviation met him from time to time, and everyone who had a sensible proposition to put before him was certain of a sympathetic hearing. If any trouble arose with regard to civil flying in any part of the world there was only one thing to do, "See Brancker about it," and it was a very rare case when he did not put the matter right, possibly by a personal letter to a foreign personage of high degree. His loss in the R.101 was a tragedy, but he had cleared the ground and laid the foundations of Empire Civil Aviation.

The best part of this book is the first half, written by Brancker himself. He writes a pleasing pure style and has much to say that is interesting. Historians of the future will read this portion for its description of War Office

conditions in the Great War and the story of the amalgamation of the two British Air Forces. The second part of the book is, mostly, by Norman Macmillan, who has done his best with the rather scanty materials available, and the narrative tends sometimes to degenerate into a list of appointments. At the end there is a number of appendices, two of which, that on the W.R.A.F. and the R.A.F., might be omitted as they have no real bearing on the subject matter of the book. There is also a useful index.

This is a book which will be read through by all who knew Brancker and by many who did not, and all of these will be better for the reading of this story of self-devotion for an ideal. But the real man seems as far off as ever, as the sense of his personal charm, his instinctive sympathy, and the feeling he induced that he was there to help, are not matters which can be explained in a book, but they remain in the memory of those who knew him.

The Care and Maintenance of Aircraft

Fourth Edition. Published by Bunhill Publications, Ltd. Price 5/-.

This book contains a series of articles on various matters concerned with aircraft maintenance and which have already appeared in "Aircraft Engineering." The different authors are all experts in the matters with which they deal and the book itself covers practically every important problem connected with its subject.

In view of the increased interest which is now being taken in the amateur construction of aircraft, the issue of this new edition is timely. It would be a good thing if it were possible to ensure that no one should attempt to construct an aeroplane until he had read it carefully. But apart from this matter, the book is an invaluable source of information to ground engineers and others who have to deal with aircraft and engine maintenance.

The Principles of Motor Fuel Preparation and Application

Vol. II. By A. W. Nash, M.Sc., and D. A. Howes, B.Sc. Published by Chapman and Hall. Price 30/-.

There was a time when petrol engines could be relied on to consume almost any type of vapourisable fuel which was available and to consume it without complaint, but this is not the case to-day. The more highly developed the petrol engine becomes, and the aviation engine is the most highly developed of any, the more necessary it is to supply the engine with the type of fuel suited to it, and a wrong selection may even result in a mechanical breakdown.

The design of aero engines and the properties of fuels are therefore matters which are interlocked, improvement in the one being largely dependent on improvement in the other. The improvements in fuel economy and lesser weight characteristic of the more modern engines would have been out of the reach of the engine designer had not the petroleum technologist prepared the way.

The properties of fuels are therefore matters of great importance to aviation. It is necessary to know, not only what fuels are available to-day, but the direction of improvement, so that advantage may be taken of it in future engine designs. That improvement has already been great is shown in certain chapters in this book, where the petrol available to-day and in previous years is compared. One of the most important discoveries ever made in this connection is that of the effect of small quantities of tetraethyl lead on the knock rating. Thanks to this substance the United States Government has issued a petrol specification demanding an octane number of 92, and doubtless many other governments will follow suit, for an engine built to take the full advantage of such a fuel would show a considerable improvement in economy.

Apart from petrol fuels the authors rightly give considerable attention to Diesel fuels. These require properties which are directly opposite to the others.

Aromatics, which are found in first class petrols, are unusable in Diesels as they give rise to knock, while the most satisfactory fuels for these engines have a paraffin base. Ethyl lead increases knock in Diesels while it prevents it in petrol engines, and those substances which encourage knock in the latter inhibit it in the former.

It follows that this is an important book. The authors are well qualified by experience to discuss the subject and they have dealt with it exhaustively in nearly all its branches and the work may be regarded as a standard text-book on the subject. It is well illustrated by diagrams and can be easily read even by those who are not specially acquainted with the subject, and considerable space is given to testing methods, the technique of which is developing rapidly. The book is an essential component of a good technical library.

A Manual of the Principles of Meteorology

R. Mountford Deeley, M.Inst.C.E., F.R.Met.S., etc. Published by Charles Griffin and Co., Ltd. Price 15/-.

It is stated in the preface that the object of this book is to place before the general reader, in simple language, the author's conception of the conditions in the atmosphere. By the term general reader is usually meant the reader who, being perhaps a business man and possibly knowing little of science, yet desires to obtain some insight into scientific matters and to keep himself abreast with progress.

It is to be feared that Mr. Deeley's volume will not be popular among this class of reader. It is not by any means easy reading and to understand the comments on some of the complicated diagrams close concentration is necessary. On the other hand, it is not intended to be a full-blooded scientific manual. It contains no mathematics, even where the use of this method of discussion would elucidate matters, and several of the theories put forward seem very speculative. The book, therefore, seems to fall between two stools.

One theory that is difficult to follow suggests that the heating of a meteor which enters the atmosphere is due to its acquiring a frontal cap of dense air heated by compression, which air melts and volatilises the meteor. It is not easy to see why such a cap should form. At the same time, for those who choose to take the trouble to read it, there is much in the book which is of interest.

CORRESPONDENCE

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY,
7, Albemarle Street, London, W.1, England.

Dear Sir,—The excellent report by J. J. Green and G. J. Klein on the "Aerodynamic Characteristics of Aircraft Skis and the Development of an Improved Design," published in the August number of the Journal terminates with an appendix which prompts a little discussion.

At the outset let me say that the four recommendations made by the authors, viz., that

1. The ski pedestal should be of the rigid type and not of the shock absorbing (oildraulic) type;
2. The ski with its rigid pedestal should be used in conjunction with a specially designed ski undercarriage instead of attempting to fit the ski to an existing wheel undercarriage;
3. If a special ski undercarriage is not possible, the wheel undercarriage shock absorbing unit should be capable of a double range adjustment—one range for use with wheels and the other range for use when wheels are replaced by skis (the ski pedestal being of the rigid type);
4. The ski trimming gear should be enclosed in the ski itself and should operate on the axle. External trimming cables, due to their very high resistance, should be avoided;

represent a counsel of perfection and as such are unassailable. There are, however, certain practical considerations which render the ideal solution too difficult or too costly to be attained.

Take, for example, the military aeroplanes of the fighter, army co-operation and day bomber classes belonging to any power in the temperate zone. These aircraft spend their lives as wheeled landplanes, but should, at a moment's notice, be capable of preparation for operation on snow. In order to maintain a high state of preparedness and mobility and at the same time observe the dictates of economy, it is desirable to reduce to the smallest possible the number of operations required to convert from landplane to skiplane, and also to reduce the quantity of special components that have to be held in stock. This is a strong argument in favour of a ski which can be used as a direct and simple replacement of a wheel without a change of undercarriage.

Recommendation number 3 has much merit and would probably be the correct solution in the more northern countries where ski operation represents a substantial proportion of the aircraft life. In the matter of expense, it is admitted that the capital cost of a shock absorbing ski pedestal is probably a little greater than that of the necessary modification to the standard shock absorbing unit, but it seems a pity to carry the extra weight of the latter about in the air all the time on account of a mere possibility that it might be useful sometime. The ski pedestal stays in storage until required and demands no more than ordinary storage maintenance. Another argument against the double range shock absorbing unit for a temperate zone Air Force is that only a certain proportion of the effective aircraft strength would ever be employed on skis, and consequently it is better to concentrate the conversion parts into one com-

ponent which can be stocked in the quantities deemed necessary without affecting the standardisation of the entire landplane equipment on the strength.

In enumerating the advantages of a rigid pedestal over a flexible pedestal, the authors of the report make the following statement:—

> "With a rigid pedestal the problem of internal trimming can be solved easily. In the case of a flexible pedestal this problem is very difficult."

With this statement I disagree entirely because the simplest solution of the trimming problem that has yet been achieved has been rendered possible by virtue of the deflection of a shock absorbing pedestal. When the National Research Council had evolved a desirable ski shape, it was decided to have a practical full-scale trial on a "Hawker Audax" and a pair of skis of suitable size was constructed to the recommended lines. Calculations showed that the trimming force, even with the much improved pitching moment characteristics of the new skis, would reach a magnitude in a high speed dive which, with the ordinary elastic type of restraining device, would necessitate a heavy and complicated system of springs. The trouble is that for taxying the restraint should be as little as possible whereas in flight it should, under the worst conditions definitely overrule the upsetting moments. The answer obviously was to produce a device which would only come into effect in flight and would lock the ski rigidly in the desired position. Furthermore, the operation had to be automatic, to relieve the pilot of any responsibility, and had to be simple. The idea of using the extension of the elastic leg of the pedestal as the weight of the aeroplane becomes airborne was hit upon, and this is how it is put into effect. A strong lever carrying a hardened steel roller on a horizontal axis at its lower end is mounted nearly upright on the brake flange and secured against rotation relative to the airframe by means of the brake torque strut used with the ordinary wheel undercarriage. To the base of the ski are securely attached a pair of rigid brackets joined across their tops by a flat piece of steel on edge and lying longitudinally with the ski. This piece, which is called the trimming quadrant, has for its under edge a special profile based on a true circle described from the axle as centre. The roller on the trimming lever engages with the bottom profile of the trimming quadrant and at the position corresponding to the desired attitude in flight, the profile takes a sharp drop of such a depth that, as long as the roller is bearing on the profile, it cannot pass the "step." For approximately fifteen degrees ahead of the step, the profile follows a true circle about the axle and then begins to withdraw with increasing rapidity. Behind the step the profile again withdraws like a cam in relation to the axle. When one quarter of the weight of the aeroplane is acting on the two skis, the rollers on the trimming levers are depressed away from the profile, and there is complete freedom of rotation within the wide limits of the trimming quadrant brackets except for the mild restraint of an anti-chatter spring. As soon as the aeroplane becomes airborne, the trimming roller, which with the tail of the fuselage slightly depressed for take-off, is a few degrees in advance of the step, comes to bear against the quadrant profile, and as the pitching moment on the ski is positive at all angles upwards from 12½ degrees negative incidence, the step of the quadrant is forced against the roller and remains there. In the unlikely event of the ski nose becoming sufficiently depressed to produce negative pitching moments, the roller will bear against the rising cam forward of the step, and any increasing depression of the ski nose will be forced to produce a compression of the pedestal leg. Thus any shock on the limit stops is averted.

During an ordinary tail down landing, the quadrant is free to move about the roller over the fifteen degrees of circular profile, and this is sufficient to let the tail well down, with a reasonable allowance for irregularities of the ground, by which time the weight of the aeroplane will disengage the "lock." If, by

any chance, the nose of the ski should strike a bump when the aeroplane is just about to be airborne, the impact will be enough to compress the pedestal leg to a sufficient extent to allow the roller to override the step. The fast rising cam behind the step will absorb any further shock and will return the quadrant to its proper position as soon as the aircraft is properly airborne.

The position of the roller relative to the airframe, and consequently the attitude of the ski, can be accurately adjusted by means of the adjustable brake torque strut. As a first trial, the angle chosen was plus 3° relative to the thrust line of the airscrew, as this corresponded to the angle of minimum drag in the wind tunnel.

It is true that the arrangement described above necessitated a flexible helmet of approximately streamline shape to house the brake flange and the tops of the trimming lever and pedestal. This helmet requires development and refinement, but it is felt that its drag is a small price to pay for the generally good compromise achieved.

The preliminary trials were made with external steel safety cables attached to the nose and tail of the skis and reefed with a thin copper wire. After a period of aerobatics the copper wire was completely unaffected, so the safety cables were removed for all subsequent flights. The speed with the streamline skis was about 162 m.p.h. as compared with 154 m.p.h. with ordinary skis.

The reader should bear in mind that all the foregoing discussion applies only to aircraft with a fixed type of undercarriage. In my opinion the problem of ski equipment for retractable undercarriages has two distinct sides. On those undercarriages which retract about a thwartships axis the crudest type of ski and trimming gear will probably be the best, as in flight it can all be tucked up out of the way against the bottom of the wing in simple fashion and during landing the drag will probably be advantageous. Weight will be the primary consideration. On undercarriages which retract about a longitudinal axis the problem is very difficult indeed and I hesitate to venture any predictions beyond the weak admission that for a time at least it may prove the wisest policy to forego retraction in winter and fit a good streamline ski and shroud the legs as well as possible a la Northrop.

Yours truly,

A. FERRIER, *Squadron Leader.*

Ottawa, Canada,
September 7th, 1935.

The 595th Lecture delivered before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

Twenty-third Wilbur Wright Memorial Lecture

The Twenty-third Wilbur Wright Memorial Lecture, entitled " The Developments and Reliability of the Modern Multi-Engine Air Liner," by D. W. Douglas, Esq., President of the Institute of Aeronautical Sciences, was delivered before the Society on Thursday, May 30th, 1935, at 9.15 p.m., in the Aeronautical Section of the Science Museum, South Kensington, before a distinguished company of members and guests.

The chair was taken by Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.P., President of the Society. The function was held at the Science Museum by kind permission of the Director, Lieut.-Colonel E. E. B. Mackintosh, D.S.O.

The lecture was preceded by the annual Council Dinner at which the following were present:—

Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.P., President of the Society, in the chair.
Captain P. D. Acland.
Major B. F. S. Baden-Powell, F.R.A.S., F.R.Met.Soc., Hon. F.R.Ae.S.
Major T. M. Barlow, M.Sc., M.Inst.C.E., M.I.Mech.E., F.R.Ae.S.
Griffith Brewer, Esq., Hon. F.R.Ae.S.
Major G. P. Bulman, O.B.E., B.Sc., F.R.Ae.S.
R. S. Capon, Esq., O.B.E., B.A., F.R.Ae.S.
C. E. Colvin, Esq. (Member of Council, Institute of Aeronautical Sciences, U.S.A.).
H. Roxbee Cox, Esq., Ph.D., D.I.C., B.Sc., A.F.R.Ae.S.
Captain M. J. B. Davy, A.F.R.Ae.S.
Donald W. Douglas, Esq. (President, Institute of Aeronautical Sciences, U.S.A.).
Air Vice-Marshal Sir Hugh Dowding, C.B., C.M.G. (Air Member for Supply and Research).
E. C. Gordon England, Esq., F.R.Ae.S.
C. R. Fairey, Esq., M.B.E., F.R.Ae.S. (Past-President, Royal Aeronautical Society).
Mynheer Anthony Fokker.
Lord Gorell, C.B.E., M.C. (Chairman, Royal Aero Club).
Captain the Rt. Hon. F. E. Guest, C.B.E., D.S.O., M.P.
Professor F. T. Hill, F.R.Ae.S., M.I.Ae.E.
Professor G. T. R. Hill, M.C., M.Sc., F.R.Ae.S.
J. E. Hodgson, Esq., Hon. F.R.Ae.S.
Major D. H. Kennedy, O.B.E., F.R.Ae.S.
Captain A. G. Lamplugh, M.I.Mech.E., F.R.G.S., F.R.Ae.S., M.I.Ae.E.
The Most Hon. the Marquess of Londonderry, K.G., M.V.O. (Secretary of State for Air).
Colonel E. E. B. Mackintosh, D.S.O. (Director, Science Museum).
Sir Robert McClean (Chairman, Society of British Aircraft Constructors).
Major R. H. Mayo, O.B.E., M.A., A.M.Inst.C.E., F.R.Ae.S.

Sir Joseph Petavel, K.B.E., D.Sc., F.R.S., F.R.Ae.S. (Director, National Physical Laboratory).
Dr. N. A. V. Piercy, M.I.Mech.E., A.M.Inst.C.E., F.R.Ae.S.
Captain J. Laurence Pritchard, Hon. F.R.Ae.S. (Secretary, Royal Aeronautical Society).
D. R. Pye, Esq., M.A., M.I.Mech.E., F.R.Ae.S.
W. P. Savage, Esq., A.M.I.Aut.E., A.F.R.Ae.S.
O. E. Simmonds, Esq., M.A., F.R.Ae.S., M.I.Ae.E., M.P.
Lieut.-Commander L. C. Stevens, U.S.N. (Assistant Naval Attaché, Aviation, U.S.A.).
Professor Wm. Thornton, O.B.E., D.Sc., D.Eng. (President, Institution of Electrical Engineers).
H. E. Wimperis, Esq., C.B.E., M.A., M.I.E.E., F.R.Ae.S. (Director of Scientific Research).
Lawrence A. Wingfield, Esq., M.C., D.F.C., A.R.Ae.S.I.

Immediately following the reading of the lecture the Society held a Conversazione in the Science Museum, at which a very large number of the Society's members and friends and many distinguished guests were present. During the evening, by kind permission of the Air Council, the band of H.M. Royal Air Force, conducted by Flight Lieutenant R. P. O'Donnell, M.V.O., played selections. The following is a list of those who attended the Conversazione and the lecture, in addition to the Council and their guests:—

C. F. Abell, Esq., O.B.E., A.F.R.Ae.S. (and three guests); Mrs. P. D. Acland; David R. Adams, Esq., A.F.R.Ae.S.; Mrs. D. R. Adams; Capitaine de Corvette V. A. M. Albertas (French Air Attaché); Madame Albertas; R. M. Alcock, Esq., A.F.R.Ae.S.; Major J. W. Kidston Allsop, M.Inst.C.E., M.I.Mech.E., M.Const.E., A.F.R.Ae.S. (and one guest); R. P. Alston, Esq.; Mrs. R. P. Alston; Captain the Earl Amherst, M.C. (and one guest); E. John Andrews, Esq.; Major Lord Apsley, D.S.O., M.C., M.P.; the Lady Apsley; Engineer-Captain Natal Arnaud (Brazilian Assistant Naval Attaché); Madame Natal Arnaud; R. Arnison, Esq.; Mrs. R. Arnison; Captain J. F. Arnold, B.Sc., A.F.R.Ae.S.; Mrs. J. F. Arnold; Dr. L. Aitchison.

Major C. J. P. Ball, D.S.O., M.C., A.F.R.Ae.S. (and two guests); F. Rodwell Banks, Esq., O.B.E., A.M.I.A.E., F.R.Ae.S.; Mrs. Rodwell Banks; Captain F. S. Barnwell, B.Sc., O.B.E., A.F.C., F.R.Ae.S.; F. S. Barton, Esq. (and two guests); Miss F. Barwood; E. L. Bass, Esq., A.F.R.Ae.S.; Mrs. E. L. Bass; H. Bateman, Esq., A.C.G.I., B.Sc., D.I.C., A.F.R.Ae.S.; Mrs. Bateman; A. S. Batson, Esq.; Dr. Phillippe Bauwens; D. M. Bay, Esq.; Miss Beaks; Her Grace the Duchess of Bedford, D.B.E.; F. A. Connop Behenna, Esq.; Hans Belart, Esq., A.F.R.Ae.S.; E. N. B. Bentley, Esq., A.C.G.I., A.F.R.Ae.S.; Squadron Commander James Bird, O.B.E., F.R.Ae.S.; Robert Blackburn, Esq., O.B.E., A.M.Inst.C.E., M.I.M.E., F.R.Ae.S. (and three guests); Mrs. V. T. Blackburn; Leonard Bloomer, Esq.; Group Captain R. J. Bone, C.B., D.S.O.; Ivor Bowen, Esq., M.Sc., A.F.R.Ae.S.; Miss F. B. Bradfield, M.A., A.F.R.Ae.S.; M. L. Bramson, Esq., A.C.G.I., A.M.I.Mech.E., F.R.Ae.S. (and one guest); Cyril Griffith Brewer, M.A. (Cantab.), A.F.R.Ae.S.; J. E. Breyer, Esq.; R. Bridges, Esq.; Group Captain E. F. Briggs, D.S.O., O.B.E., F.R.Ae.S. (and one guest); Mrs. E. F. Briggs; Captain J. C. Briggs; Air Chief Marshal Sir Robert Brooke-Popham, K.C.B., C.M.G., D.S.O., A.F.C.; Lady Brooke-Popham; Air Vice-Marshal F. W. Bowhill, C.M.G., D.S.O. (Air Member for Personnel); Wing Commander Vernon Brown, M.A., F.R.A.S., A.F.R.Ae.S.; Mrs. Vernon Brown; Squadron Leader G. M. Bryer, O.B.E., A.F.C., A.F.R.Ae.S.; Mrs. G. M. Bryer; R. G. Buck, Esq.; Major G. P. Bulman, O.B.E., B.Sc., F.R.Ae.S.; Mrs. G. P. Bulman; P. W. S. Bulman, Esq., M.C., A.F.C., F.R.Ae.S. (and one guest); Group Captain A. B. Burdett, D.S.O.

(Secretary, R.A.F. Club); Squadron Leader C. G. Burge, O.B.E., A.R.Ae.S.I.; A. F. Burke, Esq.; A. S. Butler, Esq.; Mrs. A. S. Butler.

Brigadier-General W. B. Caddell (and three guests); J. D. Campbell, Esq., B.Sc., A.R.T.C., A.F.R.Ae.S.; Mrs. J. D. Campbell; Miss Constance Campbell; Mrs. R. S. Capon; Mrs. Bonham Carter; Wing Commander T. R. Cave-Browne-Cave, C.B.E., M.I.Mech.E., M.Inst.N.A., F.R.Ae.S.; Air Commodore J. A. Chamier, C.B., C.M.G., D.S.O., O.B.E.; Mrs. J. A. Chamier; Miss M. Chapman; Captain L. W. Charley, O.B.E.; Miss L. Chitty, F.R.Ae.S.; Herbert Chitty, Esq., F.S.A.; C. R. Chronander, Esq.; W. M. Churchill, Esq.; Richard M. Clarkson, Esq., B.Sc., A.C.G.I., A.F.R.Ae.S.; Sir Alan J. Cobham, K.B.E., A.F.C., Hon. F.R.Ae.S.; Lady Cobham; Squadron Leader S. N. Cole, A.F.R.Ae.S.; Mrs. Cole; W. S. Coleman, Esq.; C. B. Collins, Esq., A.R.Ae.S.I. (and one guest); Lieut.-Commander C. N. Colson (*Flight*); J. V. Connolly, Esq., B.E., A.F.R.Ae.S.; Hayne Constant, Esq., M.A., A.F.R.Ae.S.; F. J. Costigan, Esq.; Miss G. Cottrell (and one guest); Miss M. H. Cournelle; Captain W. Courtney (*Evening Standard*); Mrs. D. M. Roxbee Cox; F. F. Crocombe, Esq., A.C.G.I., D.I.C., B.Sc., A.F.R.Ae.S.

E. A. Dasnieres, Esq.; Mrs. M. M. Dasnieres; W. Davidson, Esq.; Graham Dawbarn, Esq., M.A., F.R.I.B.A., M.I.Struct.E., A.F.R.Ae.S. (and one guest); R. P. G. Denman, Esq., M.A., A.F.R.Ae.S.; Mrs. Roderick Denman; Ambrose Desant, Esq.; W. C. Devereux, Esq., A.F.R.Ae.S.; Mrs. W. C. Devereux; D. C. Douglas, Esq., A.R.Ae.S.I. (and one guest); Mrs. D. W. Douglas; Miss Douglas; Mr. Douglas, Jnr. (2); George N. Douglas, Esq., D.S.C., M.C., A.F.R.Ae.S.; Captain R. Douglas; W. D. Douglas, Esq., F.R.C.Sc.I., A.F.R.Ae.S.; Commander J. S. Dove, R.N.

Norman Edgar, Esq.; Mrs. Edgar; F. J. Edmunds, Esq.; H. S. Ellis, Esq.; A. H. Emden, Esq.; D. J. Emerson, Esq.; Mrs. Gordon England; Miss D. Gordon England; S. H. Evans, Esq., M.I.Ae.E., A.F.R.Ae.S.; Mrs. S. H. Evans.

Richard Fairey, Esq.; Gerald Farquharson, Esq.; A. H. R. Fedden, Esq., M.B.E., M.I.A.E., M.S.A.E., F.R.Ae.S. (and two guests); A. Fedden, Esq.; Mrs. A. Fedden; Lieut.-Colonel L. F. R. Fell, D.S.O., O.B.E., F.R.Ae.S.; Lady Daphne Finch-Hatton; E. G. Fischeles, Esq.; Captain Trigona della Floresta, D.Sc. (Air Attaché, Italian Embassy); E. A. L. Ford, Esq.; R. Vaughan Fowler, Esq.; H. E. Fozard, Esq., M.B.E., A.M.I.Mech.E., A.F.R.Ae.S.; Mrs. J. D. Fullerton (and one guest); J. M. Furnival, Esq., M.B.E., A.F.R.Ae.S. (and one guest); Miss A. Farrington; Miss F. Farrington.

Lieut.-Commander B. W. Galpin, R.N.; Mrs. B. W. Galpin; F. Snowden Gamble, Esq. (and one guest); C. E. Gardner, Esq., A.R.Ae.S.I.; I. J. Gerard, Esq., M.Sc., A.F.R.Ae.S.; Mrs. I. J. Gerard; E. C. Gibbons, Esq., A.F.R.Ae.S.; Mrs. E. C. Gibbons; Mrs. L. H. Gibbs; Captain H. R. Gillman, A.F.R.Ae.S. (Secretary, Society of British Aircraft Constructors); Mrs. Gillman; K. B. Gillmore, Esq.; Mrs. A. E. Gillmore; Dr. Glasspoole, M.Sc. (Hon. Sec., Royal Meteorological Society); E. S. Godivala, Esq.; Lieut.-Colonel E. Gold (President, Royal Meteorological Society); Mrs. Gold; Lady Gorell; Miss Pauline Gower; Major Nabholz Grabow; Ronald O. M. Graham, Esq. (and one guest); A. W. Grant, Esq.; G. W. T. Gray, Esq.; Hugh Gray, Esq.; E. J. Gregson, Esq.; C. G. Grey, Esq. (Editor, *The Aeroplane*); Mrs. C. G. Grey; P. T. Griffith, Esq., A.F.R.Ae.S.; W. T. Griffiths, Esq.; Mrs. W. T. Griffiths; Brigadier-General P. R. C. Groves, C.B., C.M.G., D.S.O., A.F.R.Ae.S.; Mrs. P. R. C. Groves; the Hon. Mrs. Guest; P. Guilonard, Esq.

Raoul Hafner, Esq.; Major F. B. Halford, F.R.Ae.S. (and one guest); A. H. Hall, Esq., C.B.E., M.Inst.C.E., M.I.Mech.E., F.R.Ae.S.; Mrs. Hall; A. S. Halliday, Esq., Ph.D., B.Sc., D.I.C., A.F.R.Ae.S.; Edward Halliday, Esq.; Mrs. E. Halliday; F. W. Halliwell, Esq., A.M.I.A.E., A.F.R.Ae.S.; Mrs. Halliwell; Thomas Hamilton, Esq. (and two guests); Miss E. Harker;

J. A. G. Haslam, Esq., M.C., D.F.C., M.A., A.F.R.Ae.S.; Mrs. Haslam; Captain G. de Havilland, C.B.E., A.F.C., F.R.Ae.S.; Mrs. G. de Havilland; J. F. C. Haydon, Esq.; Mrs. E. L. Haydon; M. Herod Hempsall, Esq.; H. G. Herrington, Esq.; Mrs. Herrington; H. A. Hetherington, Esq.; Mrs. H. A. Hetherington; Engineer Rear-Admiral W. Scott Hill; W. I. Scott Hill, Esq.; Mrs. J. E. Hodgson; John L. Hodgson, Esq., B.Sc., A.F.R.Ae.S.; Mrs. J. L. Hodgson; Miss Mary Hodgson; Miss Honer; L. A. Howard, Esq.; H. E. Hudson, Esq., A.F.R.Ae.S. (and two guests); A. J. Hughes, Esq., O.B.E., A.F.R.Ae.S.; Mrs. Arthur Hughes; Francis Hughes, Esq.; Dr. L. E. C. Hughes; C. E. Woods Humphery, Esq. (and one guest); S. Humphries, Esq.; Group Captain G. B. Hynes, D.S.O., R.A.F.; Mrs. Hynes.

G. R. Irvine, Esq., A.M.I.Ae.E.; Miss Irvine; H. B. Irving, Esq., B.Sc., F.R.Ae.S.

C. H. Jackson, Esq.; Thurstan James, Esq.; Mrs. Thurstan James; W. G. Jennings, Esq., B.Sc., A.F.R.Ae.S.; Mrs. W. G. Jennings; Jersey Airways (four guests); L. W. Johnson, Esq., M.C., M.I.A.E., A.F.R.Ae.S.; Mrs. L. W. Johnson; A. J. T. Jones, Esq.; Mrs. Jones; Brindley R. S. Jones, Esq.; J. L. B. Jones, Esq., B.Sc.; E. Jordan, Esq., A.R.Ae.S.I.; Mrs. E. Jordan.

W. Kaeppeli, Esq.; C. Kauffmann, Esq.; Mrs. C. E. Kauffmann; Mrs. D. H. Kennedy; Miss Kennedy; F. R. B. King, Esq.; E. Gibson Knight, Esq.; M.I.P.E., A.F.R.Ae.S.

Dr. G. V. Lachmann, A.F.R.Ae.S.; Mrs. Lachmann; Dr. H. R. Lang (Secretary, Institute of Physics); Mrs. Lang; M. Langley, Esq., A.M.Inst.N.A., M.I.Ae.E.; Mrs. Langley; Mrs. Lanzerotti-Spina; W. Lappin, Esq. (and eight guests); H. Leaderman, Esq.; Captain G. A. Lingham; K. A. De Lisser, Esq., B.A.; R. M. Lloyd, Esq.; Christopher N. H. Lock, Esq., M.A., F.R.Ae.S.; Mrs. N. H. Lock; W. F. Locke, Esq.; Lady Londonderry; J. M. Longley, Esq.; A. C. Lovesey, Esq., B.Sc., A.F.R.Ae.S. (and one guest); Mrs. E. M. Lowe, J.P.; G. Lyon, Esq., M.Sc., A.F.R.Ae.S.; Colonel Sir Henry Lyons, F.R.S. (President, The Institute of Physics); Lady Lyons.

J. W. Maccoll, Esq., B.Sc., Ph.D., A.F.R.Ae.S.; W. G. Macdonald, Esq.; Mrs. W. G. Macdonald; W. R. McWilliam, Esq.; R. F. H. Mancey, Esq.; Marcus D. Manton, Esq.; Lieut.-Colonel W. Lockwood Marsh, O.B.E., M.A., LL.B., F.R.Ae.S., M.S.A.E.; Lieut.-Colonel M. Maruyama (Japanese Military Attaché); E. M. Matthews, Esq.; Ivor McClure, Esq. (and five guests); Major J. R. McGrindle; Mrs. J. R. McGrindle; Major R. H. S. Mealing, A.R.Ae.S.I.; Mrs. R. H. S. Mealing; John Millar, Esq. (and one guest); C. A. Miller, Esq.; Mrs. C. A. Miller; T. P. Mills, Esq. (and one guest); D. P. Milne, Esq.; P. H. Milne, Esq.; the Hon Arthur de Moleyns (and one guest); Captain J. W. Monahan; Mrs. Moore-Brabazon; Miss C. E. Morris; H. H. Morris, Esq.; Mrs. Morris; J. T. Morton, Esq., A.F.R.Ae.S.; — Morton, Esq.; F. J. Murdoch, Esq.

P. P. Nazir, Esq., M.Inst.B.E., A.F.R.Ae.S.; A. Nevill, Esq., A.M.I.Ae.E.; Mrs. Nevill; Mrs. Niblett; Lieut. N. Nicholas, M.I.Ae.E.; Nigel Norman, Esq., F.R.Ae.S.; Mrs. Norman; Miss Rosalind Norman; N. S. Norway, Esq., B.A., F.R.Ae.S.; Major-General A. Nyssens (Belgian Military Attaché); Madame A. Nyssens.

Dr. Ormond; J. S. L. Oswald, Esq., B.Sc., M.I.Ae.E.; Mrs. L. Oswald; Lieut.-Colonel H. W. S. Outram, C.B.E., A.F.R.Ae.S.; Mrs. Outram.

F. Handley Page, Esq., C.B.E., F.R.Ae.S.; Mrs. Handley Page; Flight Lieut. Palmer; Mrs. Palmer; Flight Lieut. L. T. Pankhurst, A.M.I.Ae.E.; J. J. Parkes, Esq.; R. J. Parrott, Esq.; Mrs. R. J. Parrott; A. T. Penman, Esq. (Reuters); Major R. E. Penny, O.B.E., A.F.R.Ae.S.; Mrs. T. Penny; E. W. Percival, Esq., M.I.Ae.E. (and three guests); Lieut.-Commander H. E. Perrin (Secretary, Royal Aero Club); Mrs. Perrin; S. C. Perry, Esq.; Major H. Petre, D.S.O., M.C.; W. E. W. Petter, Esq.; Mrs. Petter; Mrs. N. A. V. Piercy

(and one guest); R. K. Pierson, Esq., M.B.E., B.Sc., F.R.Ae.S. (and one guest); E. Pitman, Esq. (and two guests); Squadron Leader C. H. Potts, A.F.R.Ae.S.; C. M. Poulsen, Esq. (*Flight*); R. A. Powell, Esq., A.F.R.Ae.S.; Mrs. Powell; Flight Lieut. R. C. Preston, A.F.C., A.M.I.Ae.E.; Mrs. R. C. Preston; Gordon Puckle, Esq.; Mrs. Gordon Puckle; Miss L. M. Pulleine.

Miss Dorothy Quartly.

G. Rackham, Esq.; F. Radcliffe, Esq., B.Sc., A.M.A.E., A.F.R.Ae.S.; Mrs. F. Radcliffe; Dr. E. G. Rawlinson; Mrs. Rawlinson; Miss B. Rawlinson; R. Rhodes, Esq., M.I.Ae.E.; Mrs. L. Rhodes; M. C. Rigby, Esq., B.A.; A. Rigby, Esq.; T. B. Ringwood, Esq., A.M.I.Ae.E.; Mrs. Ringwood; Dr. Margaret Ritchie; H. Digby Roberts, Esq.; Miss Dorothy Roberts; John V. Roberts, Esq., A.R.Ae.S.I.; Mrs. T. Orton Roberts; E. B. Robinson, Esq., A.F.R.Ae.S.; M. Rosenberg, Esq.; A. Ryan, Esq., A.F.R.Ae.S.

Miss J. Sanders; J. M. Saunders, Esq.; Major J. C. Savage, M.B.E., M.I.Ae.E.; Mrs. J. C. Savage; J. B. S. Savage, Esq.; Mrs. W. P. Savage; Captain W. H. Sayers; Dr. A. H. Van Scherpenberg (Secretary, German Embassy); Frau Van Scherpenberg; Captain H. W. Schofield; H. A. Seyffardt, Esq., A.R.Ae.S.I. (and one guest); Eric Shaw, Esq., A.F.R.Ae.S.; B. S. Shenstone, Esq., A.F.R.Ae.S.; D. R. Sherwin, Esq.; H. E. Sherwin, Esq., F.S.I.; H. O. Short, Esq., F.R.Ae.S.; R. S. Sikes, Esq.; H. W. Sims-White, Esq., A.R.Ae.S.I.; F. Sinclair, Esq.; H. G. Small, Esq.; J. P. Smith, Esq.; H. A. Snelling, Esq.; R. Snodgrass, Esq.; H. Solomon, Esq.; Lieut.-Commander the Hon. J. M. Southwell, A.F.R.Ae.S., R.N.; the Hon. Mrs. John Southwell; Miss Dorothy Spicer, A.R.Ae.S.I.; Stanley Spooner, Esq.; Group Captain N. C. Spratt, O.B.E., A.F.R.Ae.S.; Mrs. N. C. Spratt; H. B. Squire, Esq.; A. J. Staal, Esq.; L. H. Stace, Esq.; Colonel H. Steensma; Mrs. H. Steensma; A. V. Stephens, Esq., A.F.R.Ae.S.; Lieut.-Commander L. C. Stevens; Mrs. L. C. Stevens; Major Oliver Stewart, M.C., A.F.C. (*Morning Post*); Miss Stewart (and one guest); H. J. Stieger, Esq., D.I.C., A.F.R.Ae.S.; Captain R. H. Stocken, M.I.Ae.E.; Mrs. R. H. Stocken; Major Count M. Stomm (Hungarian Military Attaché); H. Whitney Straight, Esq.; Kenneth Swan, Esq.; Mrs. Kenneth Swan.

Nigel Tangye, Esq.; — Tarris, Esq.; Mrs. Tarris; F. M. Thomas, Esq., A.F.R.Ae.S. (and one guest); S. A. W. Thompson, Esq.; Oliver Thornycroft, Esq., O.B.E., B.A., A.F.R.Ae.S.; Mrs. Oliver Thornycroft; H. M. J. Tocherns, Esq.; Commander E. D. Torén (Naval Attaché and Acting Air Attaché, Swedish Legation); Madame Torén; Dr. H. C. H. Townend, F.R.Ae.S.; D. L. Townsend, Esq. (and four guests); Major C. C. Turner, A.F.R.Ae.S. (*Daily Telegraph*); S. L. Turner, Esq.; Mrs. S. L. Turner.

Sir Alliot Verdon-Roe, O.B.E., F.R.Ae.S., M.I.Ae.E.; Air Commodore R. H. Verney, O.B.E., A.F.R.Ae.S.; C. Amherst Villiers, Esq. (and one guest); P. N. Vincent, Esq.; Mrs. J. Vincent; M. H. Volk, Esq., A.F.R.Ae.S.; G. R. Volkert, Esq., F.R.Ae.S.; Mrs. Volkert; E. Voss, Esq.; Miss B. Voyce; Air Vice-Marshal Sir Vyell Vyvyan, K.C.B., D.S.O.

J. I. Waddington, Esq.; A. H. Walker, Esq.; C. C. Walker, Esq., Assoc.M.Inst.C.E., F.R.Ae.S.; Mrs. Walker; P. B. Walker, Esq., M.A., Ph.D., A.F.R.Ae.S.; W. T. Walker, Esq.; Captain Charles E. Ward; Mrs. Ward; — Watkins, Esq.; Sir Norman J. Watson, Bart.; H. C. Watts, Esq., M.B.E., D.Sc., Assoc.M.Inst.C.E.; Mrs. Watts; Air Commodore J. G. Weir, C.M.G., C.B.E., G.C.B., F.R.Ae.S. (and two guests); Mrs. J. G. Weir; T. V. Welsh, Esq.; Mrs. Welsh; T. P. Wheeler, Esq.; Mrs. Frank Whittington; E. Weiser, Esq., B.Sc., D.I.C., A.F.R.Ae.S.; H. B. Wilkinson, Esq.; D. L. Hollis Williams, Esq., B.Sc., A.F.R.Ae.S. (and one guest); Mrs. Gardner Williams; L. C. Williams, Esq.; C. M. Williamson, Esq., C.B.E.; H. A. Wills, Esq.; Mrs. Lawrence Wingfield; C. G. H. Winter, Esq.; H. T. Winter, Esq.; R. H.

Woodall, Esq. (and one guest); A. W. Woolgar, Esq.; Colonel Warwick Wright; Major H. N. Wylie, B.Sc., M.B.E., F.R.Ae.S.

H. M. Yeatman, Esq., M.A., A.F.R.Ae.S., A.M.I.Ae.E.; Mrs. H. M. Yeatman.

The PRESIDENT (Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.P.), who received the many guests, presided at the meeting which followed for the award of medals and prizes and the delivery of the Wilbur Wright Lecture.

The following medals and prizes were presented:—

The Society's Silver Medals.

To Major F. B. Halford, F.R.Ae.S., for his work on aero engines.

To C. C. Walker, Esq., F.R.Ae.S., A.M.Inst.C.E., for his work in connection with the design of civil aircraft.

Simms Gold Medal.

To Dr. L. Aitchison, B.Sc., F.I.C., for his paper on "Light Alloys for Aeronautical Purposes."

Taylor Gold Medal.

To F. Rodwell Banks, Esq., O.B.E., F.R.Ae.S., A.M.I.Aut.E., for his paper on "Ethyl."

Busk Memorial Prize.

To H. Roxbee Cox, Esq., Ph.D., D.I.C., B.Sc., A.F.R.Ae.S., for his paper on "The Stiffness of Aeroplane Wings."

Referring to the Wright and Manly Medals, which had been awarded to Mr. F. M. Thomas, A.F.R.Ae.S., for his paper read before the Society of Automotive Engineers on "Engine Cowling and Cooling," the President remarked that these had been received through Mr. Fedden, who was a member of the International Board of Awards, and he asked Mr. Fedden to say a few words.

Mr. A. H. R. FEDDEN: He was privileged to serve on the Manly Memorial Medal Committee of the Automotive Society of America, and as this medal, together with the Wright Medal, had been presented to Mr. Thomas—an American engineer at present resident in this country—the Society of Automotive Engineers of America had sent these medals to him and had asked him to have them presented on this occasion. He had also been instructed—and it was a very great pleasure—to convey to the President, Council and Members of the Royal Aeronautical Society the greetings and best wishes of the President and Members of the Society of Automotive Engineers of America. It was appreciated by them that these two medals would be presented by the President of the Royal Aeronautical Society, and also that the presentation was to take place at this International Meeting to commemorate the memory of and to honour Mr. Wilbur Wright.

Continuing, Mr. Fedden said he had known Mr. Thomas for a very considerable time and valued the excellent work he and his collaborators had carried out on cooling and cowling of radial air-cooled engines. Therefore, he personally was delighted that Mr. Thomas had received these two famous awards for his classic work.

Mr. Fedden then handed the medals and certificates to the President and asked him to be good enough to present them to Mr. Thomas.

This completed the presentation of medals and prizes.

The PRESIDENT: It now fell to his lot to introduce Mr. Donald W. Douglas, who was to give the Wilbur Wright Lecture. Mr. Douglas was President of the Institute of Aeronautical Sciences of America and a telegram in the following terms had been received from the Secretary of that body:—

> " Institute of Aeronautical Sciences extends a hand across the sea in cordial greetings to the Royal Aeronautical Society on occasion of President Douglas delivering the Wilbur Wright Lecture. To have the President of our three-year old Society honoured by the oldest aeronautical group is a distinction appreciated here.
>
> LESTER GARDNER."

Continuing, the President said he had taken the opportunity a few days previously of sending a telegram to Mr. Orville Wright, an old friend of the Society, as follows:—

> " On Thursday next your countryman, D. W. Douglas, will deliver the Twenty-third Wilbur Wright Memorial Lecture on ' The Progress of the Air Liner,' before the Royal Aeronautical Society. I send you on behalf of the Council and members a message of cordial goodwill and appreciation of the pioneering work of your distinguished brother and yourself, work which is recalled each year on this occasion with growing admiration of the way in which you met and overcame the fundamental problems of the first power driven controlled flight in a heavier-than-air craft.
>
> MOORE-BRABAZON, *President*."

The following reply had been received:—

> " Greetings to the Council and members assembled for the Twenty-third Wilbur Wright Memorial Lecture. Development of the air liner has been an outstanding feature in American aviation. Mr. Douglas' part in this has been second to none. We are proud of him.
>
> ORVILLE WRIGHT."

Before calling upon Mr. Douglas to deliver the Wilbur Wright Lecture, he expressed appreciation of the kind permission of Colonel E. E. B. Mackintosh, Director of the Science Museum, to hold this meeting—which was the most important the Society held during the year—in this particular building in such close association with what must be by far the most important historical machine that aviation had ever known—the actual first machine to fly. Sitting there as they did in remembrance and looking at that amazing construction of wood, metal and fabric, it was perhaps difficult to realise that it was only 30 years ago that that machine was built, but already it had changed the outlook of many things in the world and of the great responsibility of all mankind to flight. It was indeed the wish not only of us in this country, but the wish of the whole world, that we should be worthy of what the Wrights did and not to reduce the whole thing to nothing else than armaments. That evening they were honouring the Wrights by listening to one who had devoted his whole life and brains to the development of fast civil aircraft. The work which Mr. Douglas had done had had a very profound effect upon the whole of aviation throughout the world. His genius and his design had upset some of those people who, although not in aviation, were a conservative type. At the same time, although Mr. Douglas and his machine were well known and advertised extensively by virtue of their merits, when they saw Mr. Douglas in the flesh they were probably a little surprised to find a very quiet, retiring and " slow " man, a very extraordinary thing. Mr. Douglas might have been a naval officer—indeed, there were lots of things he might have been, but he might have been a naval officer if his passion for aviation had not at one time made him indulge in the making of models. One particular model which he had made apparently went the wrong way and he hit the admiral on the head with it. The admiral apparently did

not like this and that stopped the development of Mr. Douglas as a sailor. Nevertheless, his keenness for aeronautics made him continue in that branch and he became one of the foremost expert engineers in the world. He had made many machines for the United States Government; from 1921 to 1934 he had sold 882 planes to the Army, 105 to the Navy, 50 to the Post Office, 13 to the Coast-guards, 90 to foreign countries and 70 for civil purposes. That made one's mouth water, added the President, and they all appreciated having before them to give this lecture one who was probably the best known designer in the world. Curiously enough, like himself, Mr. Douglas disliked flying very much, but he showed a very great wisdom in recreation in that like some of our other great designers he was fond of yachting.

Referring to the printed lecture which had been distributed among the members, the President said that Mr. Douglas had sent this along in his usual quiet way and it was very scientific and full of curves, the sort of thing which those in the Royal Aeronautical Society thoroughly enjoyed and took to bed to read. They had asked Mr. Douglas if he could turn his more technical lecture into a popular form. Mr. Douglas had consented to do that, and instead of reading the printed technical lecture he would give a talk and show a film dealing with the development of civil aviation in America, more particularly with regard to his own activities there.

THE DEVELOPMENTS AND RELIABILITY OF THE MODERN MULTI-ENGINE AIR LINER*

(with special reference to Multi-engine Airplanes after Engine Failure)

BY

DONALD W. DOUGLAS, Esq.

(President of the Institute of Aeronautical Sciences)

INTRODUCTION

Four essential features are generally required of any form of transportation: Speed, safety, comfort and economy. The airplane must compete with other forms of transportation and with other airplanes. The greater speed of aircraft travel justifies a certain increase in cost. The newer transport airplanes are comparable with, if not superior to, other means of transportation. Safety is of special importance, and improvement in this direction demands the airplane designer's best efforts.

Safety and Reliability

Statistics show that the foremost cause of accident is still the forced landing. The multi-engine airplane, capable of flying with one or more engines not operating, is the direct answer to the dangers of an engine failure. It is quite apparent, however, that for an airplane that is not capable of flying with one engine dead the risk increases with the number of engines installed. Hence, from the standpoint of forced landings, it is not desirable that an airplane be multi-engine unless it can maintain altitude over any portion of the air line with at least one engine dead. Furthermore, the risk increases with the number of

* The author wishes particularly to acknowledge the co-operation of Mr. W. Bailey Oswald in the preparation of the paper, and the generous co-operation of the various companies, testing agencies, and individuals.

remaining engines needed to maintain the required altitude. In general, therefore, the greatest safety is obtained from—

(1) The largest number of engines that can be cut out without the ceiling of the airplane falling below a required value;
(2) The smallest number of engines on which the airplane can maintain this given altitude.

Wilbur Wright.

For airplanes equipped with from one to four engines, it follows that the order of safety is according to the list below.

(*a*) Four-engine airplane requiring 1 engine to maintain given altitude.
(*b*) Three-engine ,, ,, 1 ,, ,, ,, ,, ,,
(*c*) Four-engine ,, ,, 2 engines ,, ,, ,, ,,
(*d*) Two-engine ,, ,, 1 engine ,, ,, ,, ,,
(*e*) Three-engine ,, ,, 2 engines ,, ,, ,, ,,
(*f*) Four-engine ,, ,, 3 ,, ,, ,, ,, ,,
(*g*) One-engine ,, ,, 1 engine ,, ,, ,, ,,
(*h*) Two-engine ,, ,, 2 engines ,, ,, ,, ,,
(*i*) Three-engine ,, ,, 3 ,, ,, ,, ,, ,,
(*j*) Four-engine ,, ,, 4 ,, ,, ,, ,, ,,

Reliability and safety, however, depend upon other factors. These can generally be classified as the airline over which the airplane operates, and the aerodynamic design of the airplane. The airplane designer has control of reliability in so far as he is able to modify the multi-engine design to enable it to complete its flight over the necessary terrain after engine failure.

While safety probably requires only that the airplane be able to fly to the nearest landing field with one engine out of operation, reliability of multi-engine airplanes indicates more properly the possibility of carrying on flight to the original destination without hazard and discomfort. The length of trip, altitude required, amount of fuel load that can be disposed of, percentage of power required to maintain flight, control and performance of the airplane—all these considerations must be studied before a figure of merit can be assigned to any multi-engine airplane.

The favourable position in the above table, of the two-engine airplane capable of single-engine flight is quite interesting. This type appears to offer a very valuable combination of safety and economy. Since, for a given power, the airplane drag, weight and cost increase with the number of engines, the economy of these types with more than two engines is inferior to that of the bimotor.

Where the terrain and trip length are such as to require carrying the full cargo load for long distances after the failure of an engine, and where the added reliability of continued operation after the failure of two engines is desired, the four-engine airplane appears to be most favourable. The cases (*a*) and (*b*), showing highest reliability in the table, are believed, at least for the present, to be practically unattainable with maintenance of any considerable cargo load.

Performance and Control

The most usual misconception associated with multi-engine airplanes is that the reliability increases indiscriminately with the number of engines, which, of course, is far from fact. Unless the airplane can maintain the necessary altitude under proper control after engine failure, the reliability decreases with the number of engines. It is possible, for example, through aerodynamic design of the airplane, particularly regarding the wing and control surfaces, to make a two-engine airplane more desirable than one with more engines which is not especially designed for operation after engine failure.

The performance after engine failure is more critically affected by the various characteristics of the airplane and propulsive unit than is the normal performance, principally because of the low excess of power. While this critical nature of the performance is generally found to be unfavourable, it can be of assistance to the designer because small favourable changes in the design characteristics give large improvements in performance.

The design of airplanes for operation after failure of one or more engines is definitely a critical problem. The engineer is adequately rewarded for careful design as surely as he is penalised for merely normal design of a multi-engine airplane intended for operation after engine failure.

It is evident that the most important performance characteristic after engine failure is the absolute ceiling. Rate of climb at lower altitudes will, in general, improve as the ceiling improves. Maximum velocity and cruising speed are relatively unimportant. Safety and reliability demand that the airplane be able to fly successfully over all obstacles in the line of operation.

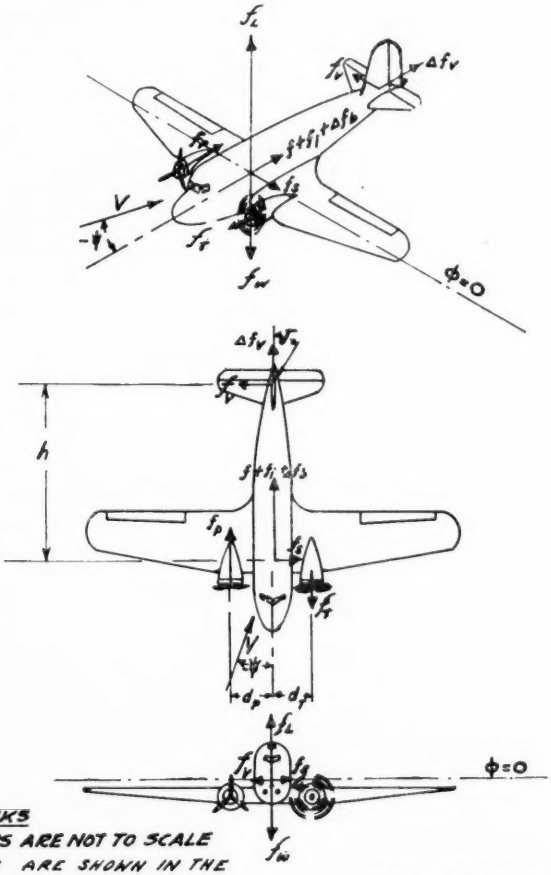
Because of the direct relation between safety and reliability of operation and flight of multi-engine aircraft on partial engine power, a prediction of such performance is of considerable interest. The present report develops a rapid parameter and chart method for determining such performance. The various contributing factors have been investigated and adjusted to check such flight test data as are available. The method is believed to produce results comparable in accuracy to flight test measurements, and has the advantages of explicitness and rapidity inherent in a chart method.

Attitude of Flight

The question naturally arises regarding the attitude of a multi-engine airplane when only part of its engines is operating, and the effect of such attitude

upon the performance characteristics. Flight tests made in this connection have served to bring out some interesting comparisons.

Three characteristic attitudes will be described, there being, of course, an infinite number of gradations between them. With adequate control, the pilot



REMARKS

1. VECTORS ARE NOT TO SCALE
2. FORCES ARE SHOWN IN THE DIRECTION OF BODY AXES
3. COSINE ψ IS ASSUMED = 1
4. SIDE FORCE ON NACELLES IS NEGLECTED
5. SECONDARY MOMENTS NOT SHOWN
6. NORMAL ANGLE OF ATTACK NOT SHOWN
7. IDLING PROPELLER ACTUALLY DOES NOT STOP UNLESS LOCKED

EQUILIBRIUM EQUATIONS

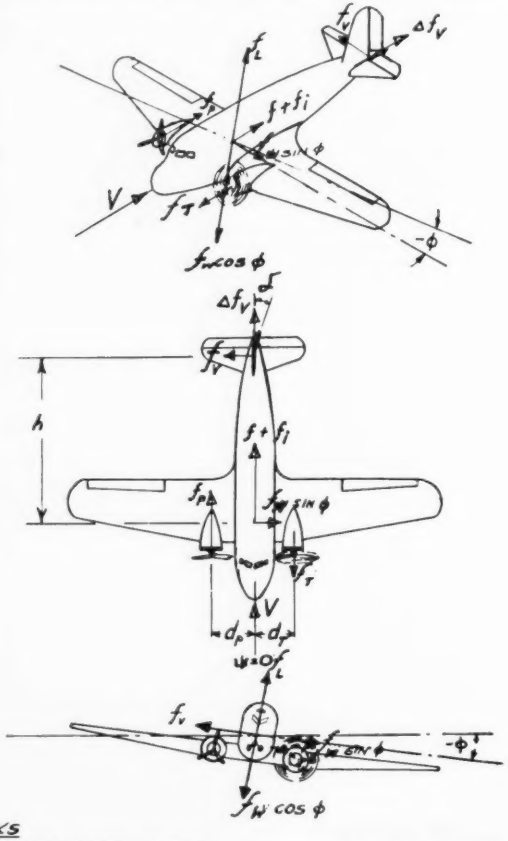
$$f_L = f+f_j+\Delta f_b+\Delta f_v+f_p = f+f_j+\Delta f+f_p$$
$$f_p h = f_p d_T + f_p d_p = (f+f_j+\Delta f)d_T + f_p(d_T+d_p)$$
$$f_L = f_W$$
$$f_s = f_V$$

FIG. 1a EQUILIBRIUM OF FORCES ON A BI-MOTORED AIRPLANE IN SINGLE ENGINE FLIGHT ATTITUDE (1) ZERO ANGLE OF BANK (WITH SKID)

will be able to choose the most efficient attitude; whereas, with inadequate control, the airplane will assume one less desirable. The three cases are illustrated in Fig. 1, and the flight test data are tabulated in Table I. The three attitudes of flight are as follows:—

1. *Zero angle of bank (with skid)*

It will be seen from Fig. 1a that the thrust and propeller set up a moment which is balanced by the rudder. The rudder side force is, in turn, balanced by the side force on the body produced by the skid. This attitude, which requires a large rudder throw, since the skid is against the rudder angle, is not always



REMARKS

1. VECTORS ARE NOT TO SCALE
2. SECONDARY MOMENTS NOT SHOWN
3. NORMAL ANGLE OF ATTACK NOT SHOWN
4. IDLING PROPELLER ACTUALLY DOES NOT STOP UNLESS LOCKED

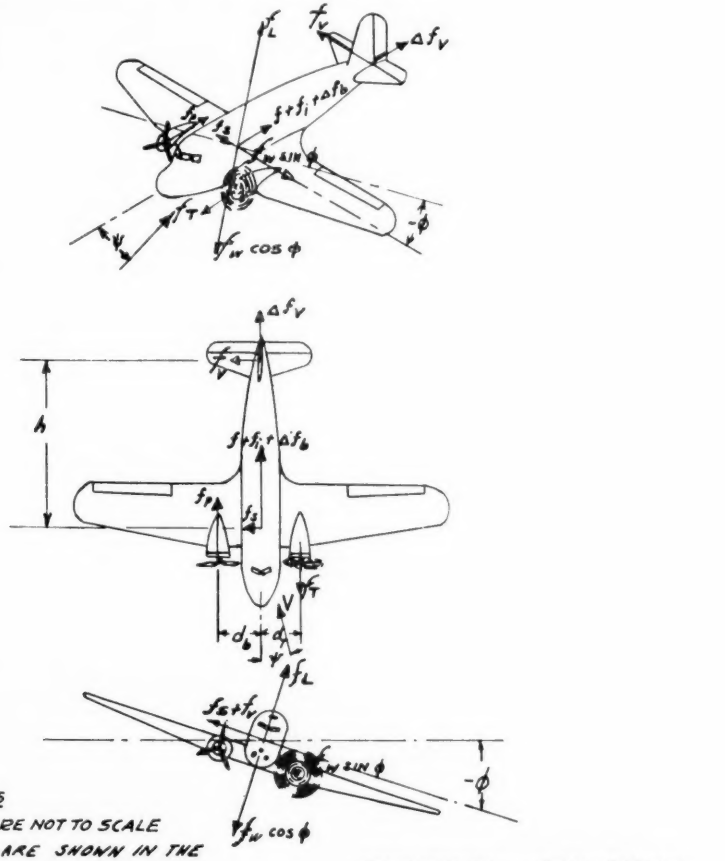
EQUILIBRIUM EQUATIONS

$$f_T = f + f_i + \Delta f_v + f_p = f + f_i + \Delta f + f_p$$
$$f_v h = f_T d_T + f_p d_p = (f + f_i + \Delta f) d_T + f_p (d_T + d_p)$$
$$f_W \cos\phi = f_L$$
$$f_W \sin\phi = f_V$$

FIG 1b. EQUILIBRIUM OF FORCES ON A BI-MOTORED AIRPLANE IN SINGLE ENGINE FLIGHT ATTITUDE (2) ZERO ANGLE OF YAW (WITH BANK)

possible of attainment if control forces are too great or if the rudder is of insufficient power. Additional drag above that in normal flight arises from the idling propeller, rudder, and body in yaw. Secondary moments and drags arise from the rudder force, moment of body, drag due to aileron angle, and additional

induced drag caused by unsymmetrical airflow over the wing. The flight test results in Table I show at zero angle of bank, 2.5° average angle of skid and 11.8° average rudder angle. Ailerons were in neutral.


REMARKS
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EQUILIBRIUM EQUATIONS
$f_T = f + f_i + \Delta f_b + \Delta f_V + f_p = f + f_i + \Delta f + f_p$
$f_T h = f_T d_T + f_p d_p = (f + f_i + \Delta f) d_T + f_p (d_T + d_p)$
$f_w \cos\phi = f_L$
$f_w \sin\phi = f_s + f_V$

FIG. 1c. EQUILIBRIUM OF FORCES ON A BI-MOTORED AIRPLANE IN SINGLE ENGINE FLIGHT ATTITUDE (3) YAW INTO ANGLE OF BANK (WITH SIDE-SLIP)

2. *Zero angle of yaw (with bank)*

In this case, as seen from Fig. 1b, the rudder side force is balanced by a component of the weight arising from the angle of bank. Calculations indicate that this angle is usually of the order of about 1° to 3°. This attitude, like attitude 1, is not possible unless the rudder is of sufficient size and the control

forces sufficiently low to permit the throw required. The rudder is responsible for all of the balancing moment, since the angle of yaw is zero. Additional drag arises principally from the idling propeller and vertical tail surface. Secondary moments and drag forces are present as before. The flight test results show at zero yaw an angle of bank of 1.5°, a rudder angle of 11°, and a slight aileron angle of 0.5° holding the lower wing down. The rudder angle is less than that for attitude 1, since the surface acts in air at zero angle of yaw and not in a skid against the angle.

3. *Yaw into angle of bank (with side-slip)*

This attitude, shown in Fig. 1c, results when there is insufficient control to attain either of the former. The airplane is side-slipped at a large angle of bank until the fin produces the balancing force needed. The side-slip develops a side force on the body which does not contribute to balancing the thrust moment, but does require additional bank in order that the weight component may balance both this body force and the side force on the vertical surface. Additional drag arises from the idling propeller, body at yaw, and the vertical surface. Secondary moments and drags are, no doubt, greatest for this case since angles of bank and yaw, and the side forces, are here greatest. The flight test data show a mean 3.0° angle of side-slip (yaw), 4.8° angle of bank, rudder angle of 10.5°, and average aileron angle of 0.5° holding the airplane into the bank. The flight test was a very mild case of attitude 3 (yaw into angle of bank) since the rudder was held hard over. It is quite apparent that with rudder free the angles of bank and yaw would increase greatly until the performance would be seriously affected.

This study of the various states of equilibrium possible brings to light several interesting facts. The attitude of the airplane in bank and yaw depends upon the unbalanced moment and the amount of rudder control that the pilot can exert and maintain with comfort. Excessive rudder control would permit flight with an outside skid and bank away from the offset thrust, while insufficient rudder control would require a large side-slip and bank toward the offset thrust. There appears to be no necessity to reach the attitude of zero bank, for zero yaw is probably the optimum from the standpoint of drag. Fortunately there seems to be little loss for small variations on either side of the zero yaw case, but extreme deficiency of rudder control would certainly lead to decreased performance resulting from high drag at the large angles of yaw and bank required.

TABLE I.

FLIGHT TEST ON ATTITUDE OF BIMOTOR AIRPLANE IN SINGLE-ENGINE FLIGHT AIRPLANE, DOUGLAS XB-7.

Gross weight 9,208lbs.

	Test A. Normal level flight. Zero bank. Engines wide open. R. Eng. & L. Eng.	Test 1. Single engine flight at zero bank. R. Eng.	Test 1. Single engine flight at zero bank. L. Eng.	Test 2. Single engine flight at zero yaw. R. Eng.	Test 2. Single engine flight at zero yaw. L. Eng.	Test 3. Single engine flight at increased angle of bank. R. Eng.	Test 3. Single engine flight at increased angle of bank. L. Eng.
Indicated air speed ...	156	104	102	104	102	104	102
R.P.M., right engine	2,450	2,120	1,100	2,120	1,100	2,120	1,050
R.P.M., left engine	2,400	1,100	2,080	1,100	2,080	1,100	2,080
Yaw meter reading ...	+15° to −° (vibrating)	3°R	2°L	0°	0°	2°L	4°R
Bank indicator ...	0°	0°	0°	1½°R	1½°L	5°R	4½°L
Rudder angle ...	1°R	13°R	12½°L	12°R	12°L	11°R	12°L
Rudder flap angle ...	0°	Full L	Full R	Full L	Full R	Full L	Full R
Aileron angle ...	1°R	1°R	1°R	2°R	1°R	3°R	0°

Performance Equations

The following analysis is based on the general parameter method of performance calculation developed in Reference 1 for airplanes with unsupercharged engines, and expanded in Reference 2 to include airplanes with supercharged engines. For an airplane operating under normal conditions, the parameters are three loadings and the major performance parameter derived from them, which are defined in the usual American and English engineering units as follows:—

$$\left.\begin{aligned} \text{Parasite loading } l_p = W/f &= \frac{\text{Weight (lb.)}}{\text{Equivalent parasite area (sq. ft.)} = C_{DP}S} \\ \text{Span loading } l_s = W/e\,(kb)^2 &= \frac{\text{Weight (lb.)}}{\text{Airplane eff. factor} \times \text{equivalent monoplane span}^2\ (\text{ft.}^2)} \\ \text{Thrust horse-power loading } l_t = W/\text{b.h.p.}_m\eta_m &= \frac{\text{Weight (lb.)}}{\text{Des. max. brake horse-power} \times \text{design max. propulsive efficiency}} \end{aligned}\right\} \quad (1)$$

Major performance parameter $\Lambda = l_s l_t^{4/3}/l_p^{\frac{1}{3}}$

The airplane efficiency factor (e) depends upon interference drag, variation from elliptical lift distribution, and variation of parasite drag with angle of attack, and varies from about 0.70 to 1.00. All the principal performance characteristics can be obtained from these parameters. Charts for this purpose are found in Reference 1.

Parameters for Flight after Engine Failure

For the performance after failure of one or more engines, it seems probable that all of these parameters are modified. The following development takes into account variations in all three of the parameters due to engine failure. It is shown later, however, that for practical purposes it is justifiable to assume that only two are changed. When sufficient data are available on maximum velocity, maximum rate of climb, and ceiling of airplanes operating with partial engine failure, the changes in the three basic parameters can be determined. Since ceilings constitute the only reliable data now available in sufficient quantity, the variations in the three parameters are somewhat uncertain, hence the final simplification given later.

Defining, for the general development,

$$\left.\begin{aligned} x &= \frac{\text{Engines in operation}}{\text{Total number of engines}} \\ y &= \frac{\text{Airplane efficiency factor after engine failure}}{\text{Normal airplane efficiency factor}} = e_x/e \\ z &= \frac{\text{Equivalent parasite area after engine failure}}{\text{Normal equivalent parasite area}} = f_x/f \end{aligned}\right\} \quad . \quad (2)$$

the performance parameters become

$$\left.\begin{aligned} l_{sx} &= l_s/y \\ l_{px} &= l_p/z \\ l_{tx} &= l_t/xT_{vx} \\ \Lambda_x &= \Lambda z^{\frac{1}{3}}/y\,(xT_{vx})^{4/3} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

For any propulsive unit, T_{vx} is the ratio of design thrust horse-power at maximum reduced-power velocity to the value at normal high speed. T_v is a function of the velocity ratio R_v, and is shown for a peak efficiency design setting of the propeller in Fig. 2. The general effect of engine failure on thrust horse-power available and required is shown on this figure. It is assumed that for the remaining engines the drop-off in thrust horse-power available with velocity

follows the normal variation. This is justified by the fact that best operation is obtained at or near zero yaw, hence the propeller is acting at or near its usual angle to the wind. Furthermore, all available information seems to indicate that the propulsive efficiency and T_v function are not appreciably affected by lateral inclination of the thrust axis. The vertical inclination will, of course, vary in the usual manner with velocity.

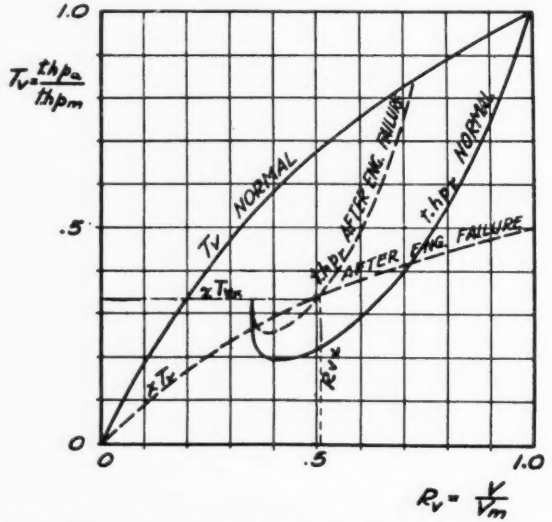


FIG. 2 VARIATION OF FULL THROTTLE THRUST HORSEPOWER AVAILABLE WITH VELOCITY. THE GENERAL EFFECT OF FLIGHT AFTER ENGINE FAILURE UPON THRUST HORSEPOWER AVAILABLE AND REQUIRED IS ILLUSTRATED

General Equation

In reference 1, the maximum velocity is shown to be given in terms of engineering parameters by the following expression:—

$$\Lambda = 52.8\,(l_s l_t / V_m)(1 - 0.332\, l_s l_t / V_m)^{\frac{1}{3}} = 52.8\,\Gamma\,(1 - 0.332\,\Gamma)^{\frac{1}{3}} \quad . \quad (4)$$

where V_m = design maximum velocity in miles per hour

$$\Gamma = l_s l_t / V_m.$$

Substituting the parameters of equation (3) for operation with engine failure into equation (4), we obtain

$$\Lambda_x = 52.8\,(l_{sx} l_{tx} / V_{mx})\,1 - 0.332\,(l_{sx} l_{tx} / V_{mx})^{\frac{1}{3}}. \quad . \quad . \quad . \quad (5)$$

Upon detailed substitution,

$$\Lambda\, z^{\frac{1}{3}} / y\,(xT_{vx})^{4/3} = 52.8\,(l_s l_t / V_m)\,(1 / yxT_{vx}R_{vx})\,[1 - 0.332\,(l_s l_t / V_m)\,(1 / yxT_{vx}R_{vx})]^{\frac{1}{3}} \quad (6)$$

where $R_{vx} = V_{mx} / V_m$.

Solving

$$\Lambda = 52.8\,[y\,(xT_{vx})^{4/3} / z^{\frac{1}{3}}]\,(\Gamma / yxT_{vx}R_{vx})\,[1 - 0.332\,(\Gamma / yxT_{vx}R_{vx})]^{\frac{1}{3}} \quad . \quad (7)$$

or,

$$\Lambda = 52.8\,(\Gamma / R_{vx})\,(xT_{vx} / z)^{\frac{1}{3}}\,[1 - 0.332\,(\Gamma / yxT_{vx}R_{vx})]^{\frac{1}{3}} \quad . \quad . \quad (8)$$

Transposing

$$\Lambda^3 / \Gamma^3 = 147{,}198\,(xT_{vx} / zR_{vx}^3)\,[1 - 0.332\,(\Gamma / yxT_{vx}R_{vx})] \quad . \quad . \quad (9)$$

or,

$$\Lambda^3 / 147{,}198\,\Gamma^3 - xT_{vx} / zR_{vx}^3 + 0.332\,\Gamma / yzR_{vx}^4 = 0 \quad . \quad . \quad (10)$$

For flight with partial engine power, x, y, z, Λ and Γ are known, assuming, of course, that the actual variations to be expected in y and z have been determined for each particular type of airplane either by flight or wind tunnel test.

Simplified Equation for Charts

In order to develop a set of charts from the general relation given in equation (10), it is necessary to know the increase in both induced drag and parasite drag when operating after engine failure. It is believed that the only way that these factors can be correctly established is through the analysis of flight test data. Flight test data on maximum velocity, maximum rate of climb and absolute ceiling are necessary to make the desired complete analysis. At present the only reliable data that are available on multi-engine airplanes are those comparing the normal absolute ceiling with absolute ceiling after engine failure. It is therefore possible to determine only one factor, that is, either y or z, from this single performance characteristic.

It has been assumed in the following development and in the charts that the induced drag in flight after engine failure is unchanged from that in normal operation; that is,

$$y = c_x/c = 1 \qquad . \quad . \quad . \quad . \quad . \quad (11)$$

This simplification is justified for performance calculations on both rate of climb and absolute ceiling for the following reason:—

> At the climbing attitude of the airplane, likewise at absolute ceiling, the induced drag and the parasite drag are approximately equal. Maximum rate of climb occurs at approximately the speed for maximum lift-drag ratio of the airplane, where the parasite and induced drags are equal. The performance variation curves of Reference 1, show that the effect on rate of climb of a change in parasite drag, calculated to give a certain difference in absolute ceiling, is approximately the same as the effect on rate of climb of a change in induced drag calculated to give a like difference in absolute ceiling. So the net effect is the same whether the necessary increase in drag is added as induced drag or parasite drag.

The assumption that all of the increase in drag is of the parasitic type gives conservative results in maximum velocity calculation, since the variation in parasite drag for a given change in absolute ceiling will have a greater effect upon the maximum velocity than would the variation in induced drag causing the same change in absolute ceiling.

In view of the limited amount of data available from flight tests, and the fact that the proper relation between absolute ceiling and rate of climb is maintained by assuming that all drag increase is parasitic, and since results on maximum velocity are somewhat conservative, it seems advisable to assume that there is no increase in induced drag and that all increases are in parasite drag.

Putting $y=1$ in equation (10), we obtain—

$$\Lambda^3/147{,}198\,\Gamma^3 - xT_{vx}/zR_{vz}^3 + 0.332\,(\Gamma/zR_{vz}^4) = 0 \qquad . \quad . \quad (12)$$

This equation is used in the development of the succeeding charts. Charts are given at the end of the paper for the cases of $x=0.5$, 0.67, and 0.75, corresponding respectively to a two-engine airplane operating on one engine, a three-engine airplane operating on two engines, and a four-engine airplane operating on three engines. Other cases can easily be derived from the equations or obtained by interpolation from the charts given in this paper.

Drag Increase After Engine Failure

Performance charts have been developed under the assumption that there is no change in the induced drag. The justification for this simplification has been given in the preceding section where it was shown that for purposes of obtaining

climb and ceiling it is permissible to assume all increases in drag as being of the parasitic type. This assumption gives conservative results on calculated maximum velocity.

There remains, therefore, to determine the total increase in the equivalent parasite drag area when the multi-engine airplane is operated with one or more engines dead. This total parasite area increase will be made up of two components: First, the drag area arising from the negative thrust of the propeller on the engine not in operation; second, that arising from the increase in drag of the airplane. This latter portion includes the induced and additional parasite drags of the rudder, the additional drag of various other parts of the airplane such as fuselage, nacelles, ailerons, and the increase in the induced drag caused by the unsymmetrical flow of air over the wing.

An investigation of the available data on the negative thrust and torque characteristics of propellers has been made in the following. Approximate relations are developed for the friction torque of engines, since the drag of the propeller depends upon the resisting torque of the engine.

Flight test data on normal ceiling and ceiling with one engine out of operation have been analysed to determine the necessary increase in equivalent parasite area required to obtain the same results by calculations.

Data and relations which are given should be regarded as approximations of preliminary nature, since the complete data necessary for defining all of these relations are not available. Complete flight test data on absolute ceiling, rate of climb, and maximum velocity of airplanes operating after engine failure would be of great assistance in determining the necessary factors for this method.

Engine Friction Torque

The friction horse-power is a complex function of many factors, but the main variation appears to be with displacement and revolutions per minute. In addition, however, the friction horse-power is affected by gearing, altitude, throttle setting, blower and compression ratios, oil temperature, and mechanical design of the engine. In Figs. 3 and 4 the friction horse-power and ratio of torque to displacement are shown for various geared and direct drive engines having different blower and compression ratios. The effects of altitude and throttle setting are illustrated in Fig. 3. These engines have displacements of from 1,340 to 1,830 cubic inches, and normal maximum power ratings of approximately 500 to 800 brake horse-power.

Flight test results indicate that the engine r.p.m. after engine failure usually assumes a value of about 35 to 50 per cent. of the rated revolutions. When friction horse-power or torque curves are not available, an approximation to the torque can be obtained by the relation,

$$Q_f = k_1 \text{ r.p.m. } \Delta\,(1 + k_2 h)\, k_3 / \text{G.R.} \quad . \quad . \quad . \quad (13)$$

where Q_f = friction torque at the propeller shaft (ft. lb.).

k_1 = constant.

Δ = engine displacement (cu. in.).

r.p.m. = engine revolutions per minute.

k_2 = constant.

h = altitude (ft.).

G.R. = gear ratio (≤ 1).

k_3 = constant (correction for geared engines).

(G.R. and $k_3 = 1$ for direct drive engines.)

Adjusting the constants according to Figs. 3 and 4, so as to give good agreement with r.p.m. in flight test, we get,

$$Q_f = 0.000057 \text{ r.p.m. } \Delta\,(1 + 0.00002h) \times [1.2/\text{G.R. if geared}] \quad . \quad (14)$$

$$Q_f/\text{r.p.m.} = 0.000057\ \Delta\,(1 + 0.00002h) \times [1.2/\text{G.R. if geared}] \quad . \quad (15)$$

$= k_4$, a constant for a given engine at any altitude.

At 9,500ft. with gear ratio of 0.687, and 1,820 cubic inch displacement,
$Q_f/\text{r.p.m.} = 0.000057 \times 1{,}820\ (1 + 0.00002 \times 9{,}500)\ (1.2/0.687) = 0.216$.

It is interesting to note that in normal full-throttle flight the torque is approximately constant; for negative thrust the friction torque is assumed proportional to the r.p.m.; and for the normal propeller load curve the torque varies as the square of the r.p.m. All of these relations are of the same general order of accuracy, often being sufficiently exact to be of much use.

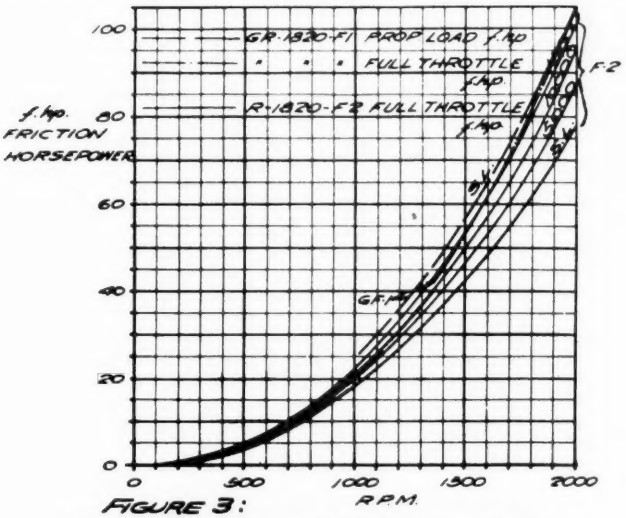
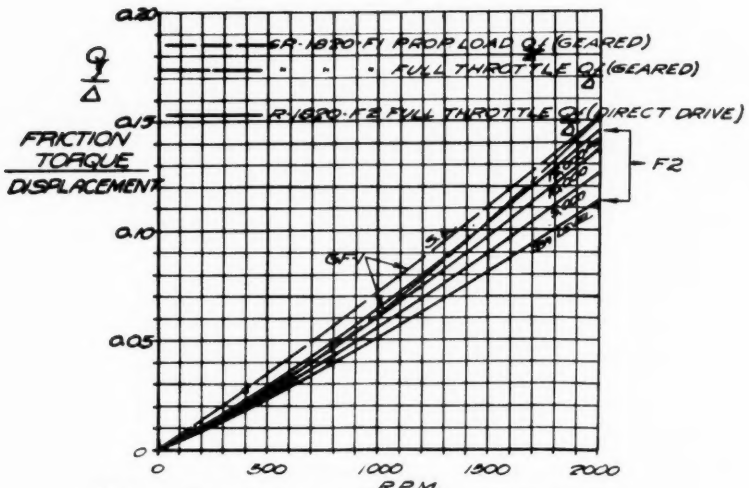


FIGURE 3:

(a) FRICTION HORSEPOWER FOR WRIGHT CYCLONE ENGINES



(b) RATIO OF FRICTION TORQUE TO DISPLACEMENT

It is recommended that engine test data be used for obtaining the torque when they are available; however, the expression for friction torque in equation (14) is believed to be sufficiently accurate for all normal calculations on performance after engine failure.

Propeller Drag

The drag or negative thrust of a given propeller depends principally upon

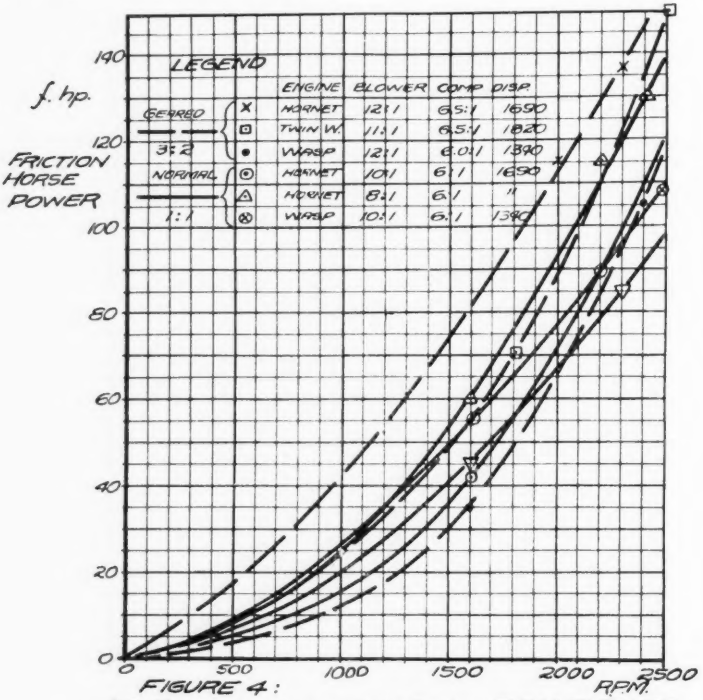
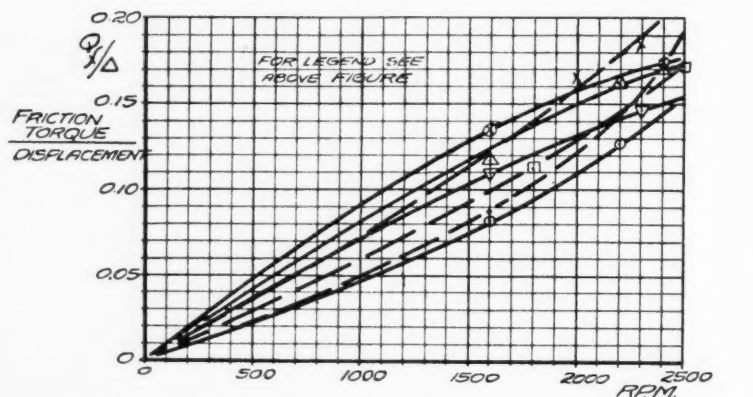


FIGURE 4:

(a) FRICTION H.P. OF VARIOUS P&W ENGINES



(b) RATIO OF FRICTION TORQUE TO DISPLACEMENT

the friction torque, velocity, blade-angle setting and propeller diameter. Wind tunnel tests on the negative thrust and torque characteristics of two-bladed propellers are reported in Reference 3, where the thrust and torque coefficients are plotted against the advance ratio reciprocal nD/V, for various combinations of wing and nacelle location.

The thrust and torque coefficients are defined by,

$$T_c = T/\rho V^2 D^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

$$Q_c = Q/\rho V^2 D^3 \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

where T = thrust (lb.) (negative sign indicates force aft).
Q = torque (ft. lbs.) (negative sign indicates propeller turning engine).
ρ = density (slugs/cu. ft.).
n = revolutions per second.
D = diameter (ft.).
V = velocity (ft./sec.).
σ = relative density.

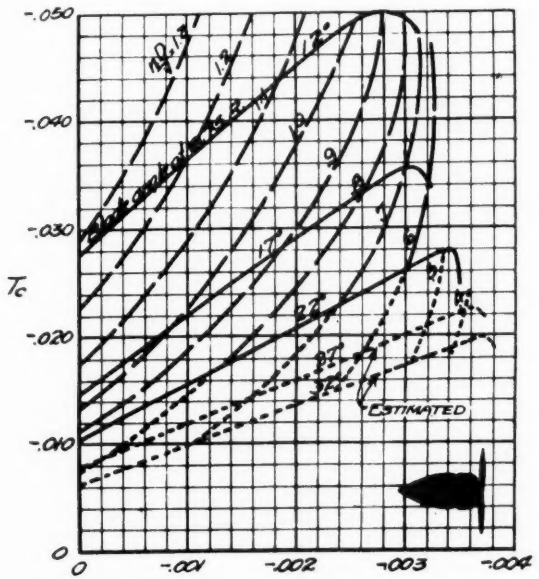


FIGURE 5:

NEGATIVE-THRUST AND TORQUE COEFFICIENTS OF A TWO-BLADED PROPELLER WITH NACELLE ALONE.

CURVES BASED ON DATA FROM NACA TECHNICAL REPORT 464.

In Figs. 5 and 6 there is plotted the negative-thrust coefficient versus torque coefficient for a two-bladed propeller with a nacelle alone, and with wing and nacelle. Fig. 6 has been estimated for the propeller 30 per cent. of the wing chord ahead of the leading edge, from two tests with the propeller located approximately 10 and 50 per cent. ahead of the leading edge of the wing chord.

The equivalent parasite drag area of the propeller can be calculated from

this curve by determining Q_c from equation (14) and obtaining T_c from Figs. 5 or 6. It is a function only of the thrust coefficient and can be obtained from

$$f_p = D_p/q = (B/2)\,(T/q) = (B/2)\,(T/\tfrac{1}{2}\rho V^2) = BD^2T_c \quad (T_c \text{ for two-bladed propeller in this equation}) \quad . \quad . \quad . \quad (18)$$

where B = number of blades.
q = dynamic pressure (lb./sq. ft.).
D_p = drag or negative thrust of propeller (lbs.).

For use in the curves, Q must be taken for two blades, since the tests were made on two-bladed propellers. For geared engines the negative torque must also be obtained for the propeller and not the engine crankshaft, hence

$$Q \text{ (for use in curves)} = (2/B)\,\{Q \text{ (engine crankshaft)/G.R.}\} \quad . \quad (19)$$

Because the engine friction torque varies with r.p.m., it may be necessary to make several successive approximations in the use of Figs. 5 or 6 before obtaining the necessary compatible conditions of torque, velocity, and r.p.m.

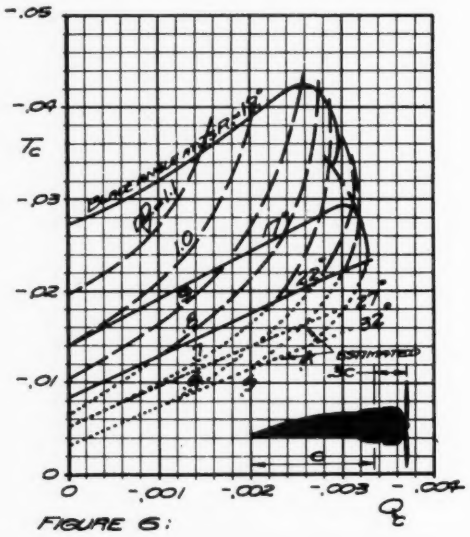


FIGURE 6:

NEGATIVE-THRUST AND TORQUE COEFFICIENTS OF A TWO-BLADED PROPELLER WITH NACELLE AND WING COMBINATION.

PROPELLER 30% OF CHORD FORWARD OF LEADING EDGE OF WING.

CURVES BASED ON DATA FROM NACA T.R. 903.

It is convenient to define a new torque-r.p.m. coefficient, Q_n, because of the linear relation between friction torque and r.p.m. The necessity of successive approximations can be eliminated by plotting the negative-thrust coefficient versus this new torque-r.p.m. coefficient, which contains the ratio Q/n instead of Q. Q_n is defined as,

$$Q_n = (Q/\rho V^2 D^3)\,(V/nD) = Q/n/\rho V D^4 = (17{,}200\ Q/\text{r.p.m.})/\sigma D^4 \text{ m.p.h.} \quad (20)$$

The ratio Q/n will have only one value, hence Q_n need not be readjusted. T_c is plotted versus Q_n in Figs. 7 and 8.

The equivalent propeller drag area, $f_p = D_p/q$, can now be determined by the following alternate methods:—

(1) Obtain Q_f/r.p.m. (or Q_f) from engine friction curves or equation (15) [or (14)].
(2) Estimate velocity, which for climb and ceiling is approximately 0 to 15 per cent. less than the normal speeds for these conditions.
(3) Calculate Q_n (or Q_c) by equation (20) [or (17)].
(4) Obtain T_c from Figs. 7 or 8 (5 or 6).
(5) Calculate f_p by equation (18).

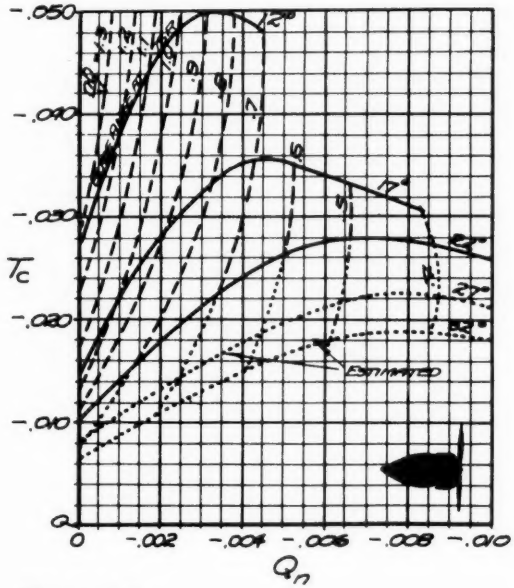


FIGURE 7:

NEGATIVE-THRUST AND TORQUE-R.P.M. COEFFICIENTS OF A TWO-BLADED PROPELLER WITH NACELLE ALONE

CURVES BASED ON DATA FROM N.A.C.A. T.R. 464.

In the event Q_c and Figs. 5 or 6 have been used, the engine revolutions, n, have to be determined from nD/V and checked with the original assumption. For Q_n, however, n determined from nD/V will be directly the correct value, provided Q/n is constant for the engine.

The drag of the propeller when locked in position, or free-wheeling, is of interest because of the possibility of decreasing or increasing the drag as desired by varying the blade-angle or negative torque. Furthermore, failure of the engine might be of such nature that the rotation of the propeller would be stopped.

The negative-thrust coefficients of the propeller when operating under various conditions have been plotted in Fig. 9.

The negative-thrust coefficient of a locked propeller decreases with increasing blade angle from -0.025 at 0° blade-angle setting at 0.75 R. to a minimum of

0.0014 at approximately 87°. Above 13° blade-angle setting the free-wheeling propeller has less drag than the locked propeller, but below 13 degrees the negative-thrust coefficient rises rapidly to a maximum of about −0.107 at 2° blade-angle setting.

An interesting comparison of the magnitude of these negative thrusts for a modern transport airplane is given in the table below:—

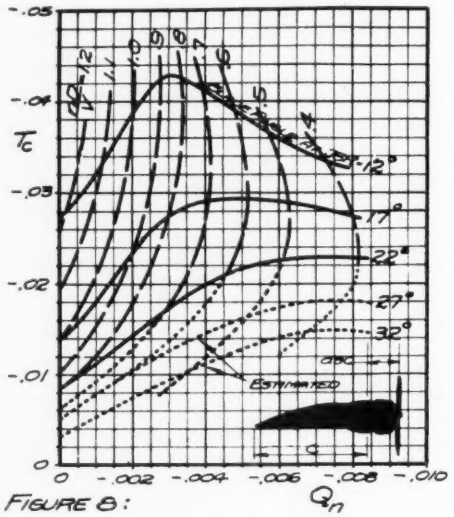


FIGURE 8:

NEGATIVE-THRUST AND TORQUE-R.P.M. COEFFICIENTS OF A TWO-BLADED PROPELLER WITH NACELLE AND WING COMBINATION - PROPELLER 30% OF CHORD FORWARD OF LEADING EDGE OF WING.

CURVES BASED ON DATA FROM N.A.C.A. T.R. 464

TABLE II.

	Equivalent Parasite Area.		% Airplane Drag.
Bimotor airplane with three-bladed 11ft. propellers	18.0		100
	One Propeller.	Two Propellers.	
Propeller 23°, turning against engine torque	4.9	9.8	27
,, 23°, locked	8.2	16.4	46
,, 23°, free-wheeling	2.6	5.2	14
,, 88°, locked	0.5	1.0	3
,, 88°, free-wheeling	0.5	1.0	3
,, 2°, locked	9.1	18.2	51
,, 2°, free-wheeling	38.9	77.8	216

Still larger negative thrusts can be obtained by adjusting both torque and blade angle, but our interest in airplane operation after engine failure is chiefly in lowest negative thrust. The feathered propeller has only about 3 per cent. of the drag of the normal airplane, while the propeller operating against normal engine friction torque would have about 27 per cent. of the normal airplane drag. Adequate propeller control is of great importance in flight of multi-engine air-

planes after engine failure, both for developing maximum positive thrust and reducing negative thrust to a minimum.

Increase in Airplane Drag

The net difference between the total drag increase and the drag of the propeller represents the increase due to the rudder, fuselage, and additional

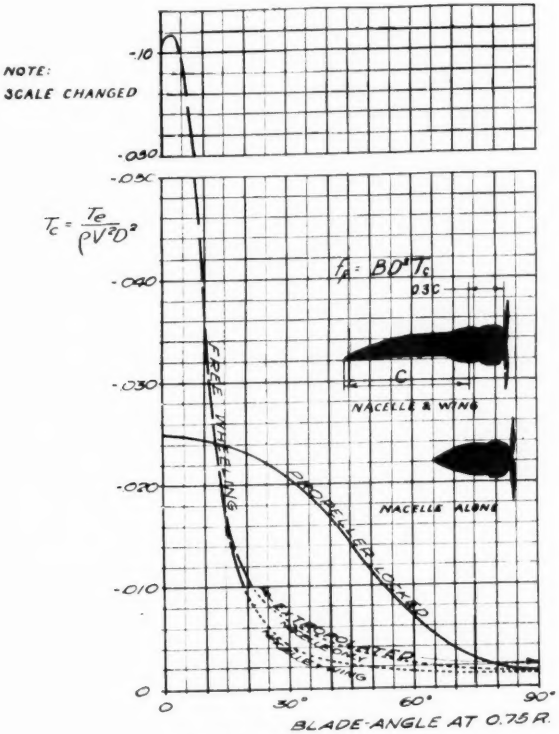


FIGURE 9:
VARIATION OF NEGATIVE-THRUST COEFFICIENT WITH BLADE-ANGLE SETTING FOR LOCKED AND FREE-WHEELING PROPELLERS.

CURVES BASED ON DATA FROM NACA. TR 464

induced drag, etc. The drag increment should be roughly proportional to the offset moment that must be balanced by the rudder. This moment arises from the eccentricity of the thrust and propeller drag.

Consider the airplane flying at approximately the attitude of zero yaw. An approximate analysis gives for the equilibrium between moments, as shown by Fig. 1,

$$f_v h = f_T d_T + f_p d_p \quad . \quad . \quad . \quad . \quad . \quad (21)$$

Solving for f_v,

$$f_v = T_v/q = (d_T/h)\,(T/q + f_p d_p/d_T) \quad . \quad . \quad . \quad (22)$$

Substituting the resisting equivalent parasite area for the equivalent thrust area, T/q,

$$f_v = (d_T/h)\,(f + f_i + f_{ex} + (1 + d_p/d_T)\,f_p + \Delta f) \quad . \quad . \quad . \quad (23)$$

where d_T = distance of centre of thrust from the plane of symmetry.
d_p = distance of centre of propeller drag from the plane of symmetry.
h = distance from centre of gravity to the centre of pressure on the vertical surface.
f_i = equivalent induced drag area $= D_i/q$.
f_{ex} = equivalent area of excess thrust.

The equivalent area of excess thrust is defined as the excess thrust for climbing divided by the dynamic pressure,

$$f_{ex} = T_{ex}/q = 550\,thp_{ex}/Vq = (W dh/dt)/Vq$$
$$= 4.5\,CW/\sigma \text{ m.p.h.}^3 \text{ in engineering units} \quad . \quad . \quad . \quad (24)$$

where T_{ex} = excess thrust (lb.).
$thpr$ = excess thrust horse-power.
W = weight (lb.).
C = rate of climb (ft./min.).
dh/dt = rate of climb (ft./sec.).

f_{ex} can be obtained from equation (24) by estimating either the excess thrust horse-power or the rate of climb. A direct estimate of f_{ex} is usually sufficiently accurate.

Assuming that the ratio of increase in airplane drag, $\Delta f/f$, is proportional to the force on the vertical surface, we get,

$$\Delta f/f = \text{function}\,[(d_T/h)\,\{\,1 + f_i/f + f_{ex}/f + (1 + d_p/d_T)\,(f_p/f)\,\}\,] \quad . \quad (25)$$
$$= \text{function}\,[F], \text{ say,}$$

which we shall approximate by a straight line,

$$\Delta f/f = A + KF \quad . \quad . \quad . \quad . \quad . \quad (26)$$

where A and K are constants depending upon the type and design of the airplane.

The relation in the brackets, F, has been chosen as the variable against which the increase of airplane drag is plotted. Forty per cent. of the span can generally be substituted for h, when the latter is not known.

The increase in airplane drag will differ for various conditions of flight as follows:—

Case.	Special Condition (approx.)	F.
Absolute ceiling ...	$f_i = f$, $f_{ex} = 0$	$(d_T/h)\,[2 + (1 + d_p/d_T)\,(f_p/f)]$
Climb	$f_i = f$	$(d_T/h)\,[2 + (f_{ex}/f) + (1 + d_p/d_T)\,(f_p/f)]$
Maximum velocity ...	$f_i = 0$, $f_{ex} = 0$	$(d_T/h)\,[1 + (1 + d_p/d_T)\,(f_p/f)]$

Calculations from flight test data on several multi-engine airplanes for the determination of the drag increase at absolute ceiling with one engine dead are given in Table III. The flight test data on normal ceiling and ceiling after engine failure have been reduced by the method here developed to determine the total parasite drag increase of the airplane. The results have been plotted in Fig. 10, which show the ratio of increase of airplane drag as a function of the factor F. The constant A varies from about 0 to 0.5, and K from about 0.4 to 1.3 respectively for airplanes of efficient and poor design for flight after engine failure.

After some experience in the use of the method, the various items making up the drag increase ratio can be estimated closely enough to bring the calculated result within the experimental error of flight test.

It will be noted in Fig. 10 that the factor F is least when the thrust and the propeller drag axes are in the plane of symmetry, and increases as both the thrust and propeller drag offsets increase. It should be remembered that the

TABLE III.

ANALYSIS OF FLIGHT TEST DATA ON CEILING OF MULTI-ENGINE AIRPLANES AFTER ENGINE FAILURE.

Airplane	Engine not operating	Normal absolute ceiling	Ceiling with one eng. not operating	Λ	f	Propeller	D	Angle at 0.75 R	V_{ex} m.p.h.	b.h.p.$_m$ (each)	Displacement	Gear ratio	σH_1
Boeing	R	24,400	6,800	7·3	23·4	3-bl.	11·5	27·7	112	600	1,860	0.667	0.816
YB-9	L	—	,,	—	—	—	—	—	(112)	—	—	—	,,
Boeing	R	21,000	3,500	10.35	27·3	3-bl.	9.83	21.5	101	600	1,570	0.714	0.902
Y1B-9	L	—	2,200	—	—	—	—	—	98	—	—	—	0.937
Douglas	R	16,100	None	16.2	26.7	2-bl.	9.0	16.2	—	350	975	1.00	—
Y1C-21	L	—		—	—	—	—	—	—	—	—	—	—
Douglas	R	20,600	2,800	10.8	23.4	2-bl.	8.44	20.2	107	600	1,570	1.00	0.921
XB-7	L	—	,,	—	—	—	—	—	—	—	—	—	,,
Douglas	R	23,300	5,500	8.2	24.9	3-bl.	9.83	21.5	110	600	1,570	0.714	0.848
XO-35	L	—	7,650	—	—	—	—	—	—	—	—	—	0.795
Douglas	R	19,500	200	12.0	23.4	2-bl.	8.5	15.5	90	430	975	1.00	0.997
XRD-1	L	—	—	—	—	—	—	—	—	—	—	—	—
Boeing	R	20,400	2,000	11.0	19.9	3-bl.	9.0	23.0	110	550	1,340	1.00	0.943
247	L	—	—	—	—	—	—	—	—	—	—	—	—
Douglas	R	25,400	9,500	6.55	18.0	3-bl.	11.0	23.0	113	710	1,820	0.687	0.750
DC-2	L	—	—	—	—	—	—	low pitch	—	—	—	—	—
Ford	C	—	9,000	—	—	—	10.0	13.9	85	430	1,340	1.00	0.762
5-AT	R	20,650	9,375	10.7	56.0	2-bl.	9.46	15.8	86	—	—	—	0.753
	L	—	5,575	—	—	—	,,	,,	94	—	—	—	0.877

TABLE III (*continued*).

ANALYSIS OF FLIGHT TEST DATA ON CEILING OF MULTI-ENGINE AIRPLANES AFTER ENGINE FAILURE.

Airplane	Eng. not operating	Q_t/r.p.m.$_p$	Q_n	T_c	f_p	f_n/f	z	Δ_t/f	Δ_t/f (Av.)	d_T/h	d_p/d_T	$F=(d_T/h)\{2+(1+d_p/d_T)(f_p/D)\}$	nD/V	R.P.M. calc.	R.P.M. eng. flight test	V_c all engs.	V_{ex}/V_e
Boeing	R	0.217	0.00233	0.135	3.6	0.15	1.83	0.68	0.68	0.27	1.0	0.62	0.60	770	720	111	1.01
YB-9	L	—	—	—	—	—	—	—	—	—	—	—	—	—	700	—	—
Boeing	R	0.161	0.00327	0.0237	4.6	0.17	1.50	0.33	0.46	0.27	1.0	0.63	0.76	960	950	—	—
Y1B-9	L	0.157	0.00316	0.0246	4.0	0.15	1.73	0.58	—	—	—	0.62	0.77	950	850	—	—
Douglas	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Y1C-21	L	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Douglas	R	0.095	0.00325	0.0215	3.1	0.13	1.56	0.43	0.43	0.26	1.0	0.59	0.74	830	—	—	—
XB-7	L	,,	,,	,,	3.1	,,	—	—	—	—	—	—	,,	—	—	—	—
Douglas	R	0.167	0.00331	0.0245	4.7	0.19	1.76	0.57	0.40	0.26	1.0	0.62	0.75	1,030	800	115	0.96
XO-35	L	0.173	0.00366	0.0255	4.9	0.20	1.43	0.23	—	—	—	0.62	0.74	1,020	800	—	—
Douglas	R	0.056	0.00206	0.0290	4.2	0.18	1.72	0.54	0.54	0.17	1.0	0.40	0.95	890	—	—	—
XRD-1	L	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Boeing	R	0.079	0.00200	0.0173	2.8	0.14	1.66	0.52	0.52	0.25	1.0	0.57	0.74	800	—	—	—
247	L	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Douglas	R	0.216	0.00300	0.0204	4.9	0.27	1.55	0.28	0.28	0.27	1.0	0.69	0.71	930	1,000	130	0.87
DC-2	L	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ford	C	0.090	0.00239	0.0350	7.0	0.13	1.65	0.52	0.52	.00	0	.00	0.94	700	850	—	0.97
5-AT	R	0.091	0.00302	0.0310	5.5	0.10	1.58	0.48	0.95	0.14	2.0	0.32	0.83	660	800	88	0.98
	L	0.085	0.00222	0.0280	5.0	0.09	2.50	1.41	—	,,	,,	0.32	0.92	800	800	—	1.07

apparently large percentage drag increase includes both the increase in parasite drag and any increase in induced drag, under the simplifying assumption which has been made.

Parasite Drag Ratio

The total drag increase ratio z needed for determining the performance is given by the sum of the various items as follows:—

$$z = f_x/f = 1 + f_p/f + \Delta f/f \quad . \quad . \quad . \quad . \quad (27)$$

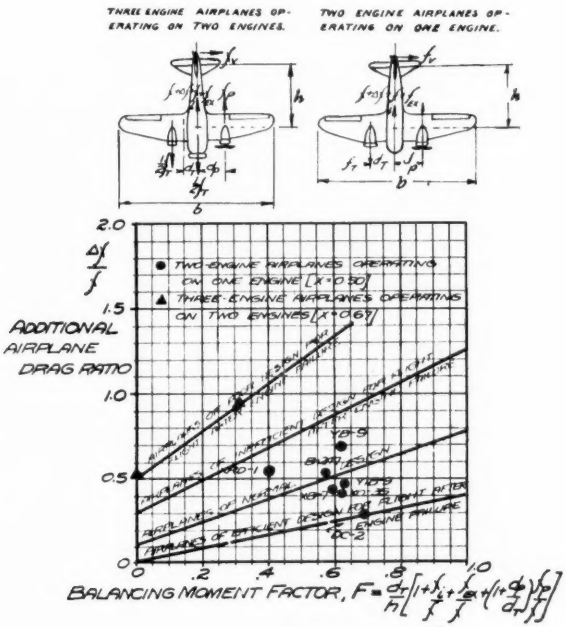

THREE ENGINE AIRPLANES OPERATING ON TWO ENGINES.
TWO ENGINE AIRPLANES OPERATING ON ONE ENGINE.
2.0
1.5
1.0
0.5
0
ADDITIONAL AIRPLANE DRAG RATIO
TWO ENGINE AIRPLANES OPERATING ON ONE ENGINE [x=0.50]
THREE ENGINE AIRPLANES OPERATING ON TWO ENGINES [x=0.67]
YB-9
B-220
Y1C-19
0 .2 .4 .6 .8 1.0
BALANCING MOMENT FACTOR, $F = \frac{d_T}{h}\left[1 + \frac{f_x}{f} + \frac{f_p}{f}(1 + \frac{d_p}{d_T})\right]$
AT CEILING: $F = \frac{d_T}{h}\left[2 + (1 + \frac{d_p}{d_T})\frac{f_p}{f}\right]$
AT V_{MAX}: $F = \frac{d_T}{h}\left[1 + (1 + \frac{d_p}{d_T})\frac{f_p}{f}\right]$
AT CLIMB: $F = \frac{d_T}{h}\left[2 + \frac{f_{px}}{f}(1 + \frac{d_p}{d_T})\frac{f_p}{f}\right]$

FIGURE 10:
ADDITIONAL AIRPLANE DRAG AS A FUNCTION OF BALANCING MOMENT FACTOR

The additional airplane and propeller drag ratios are different for the various conditions of flight. Conservative values are recommended, especially in determining rate of climb, since the high slipstream velocity often seems to cause an increase in induced drag over that normally expected.

PERFORMANCE CHARTS

Charts have been developed from equation (12) for three cases of operation of multi-engine airplanes after engine failure, namely:—

$x = 0.50$.—This case represents airplanes flying on 50 per cent. of their total number of engines, such as a two-engine airplane flying on one engine, a four-engine airplane flying on two engines, etc.

$x=0.67$.—This case represents airplanes flying on 67 per cent. of their total number of engines, such as a three-engine airplane flying on two engines, a six-engine airplane flying on four engines, etc.

$x=0.75$.—This case represents airplanes flying on 75 per cent. of their total number of engines, such as a four-engine airplane flying on three engines, etc.

Parasite drag increases of 0, 50 and 100 per cent. have been used which correspond to $z=1.0$, 1.5 and 2.0 respectively. By interpolation between the various curves the performance of other types of airplanes, under various conditions, can be closely estimated.

Curves for the performance parameters and characteristics are given in Figs. 12 to 18.

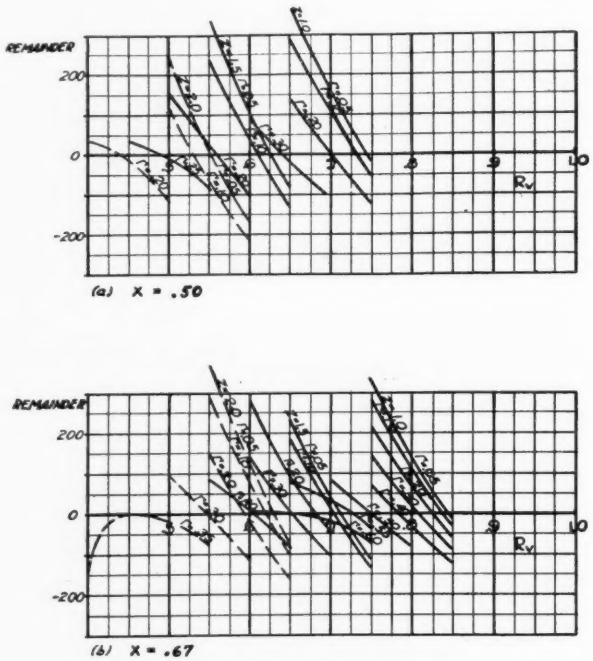


FIG. 11. CURVES FOR OBTAINING SOLUTION OF R_{vx} FROM EQUATION (12)

Development

The method of development of the charts is as follows:—

(1) For a given x, z and Λ, find the value of R_{vx} which solves equation (12). Fig. 11 shows the method of solution.

(2) From R_{vx} obtain T_{vx} by Fig. 2.

(3) Obtain the parameters for flight after engine failure from equation (3).

(4) Obtain performance from the curves of Reference 1. This process may be repeated for various values of Λ, x and z to cover the cases desired. The included charts have been worked out to cover the usual range of values of Λ, and values of x and z as noted above.

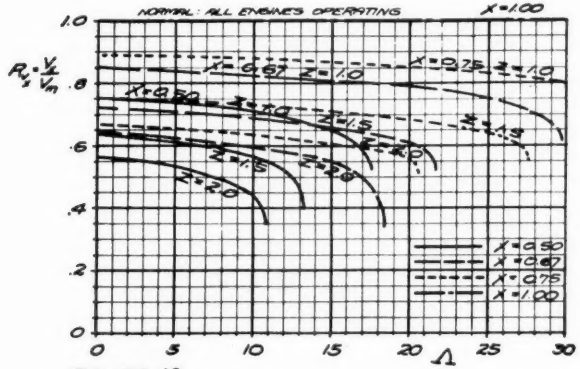


FIGURE 12.

$R_{V_x} = \frac{V_x}{V_m}$ AS A FUNCTION OF PARAMETER Λ AND PARASITE DRAG RATIO Z FOR MULTI-ENGINE AIRPLANES AFTER ENGINE FAILURE (SEA LEVEL).

X = RATIO OF NUMBER OF ENGINES OPERATING TO TOTAL NUMBER AVAILABLE.

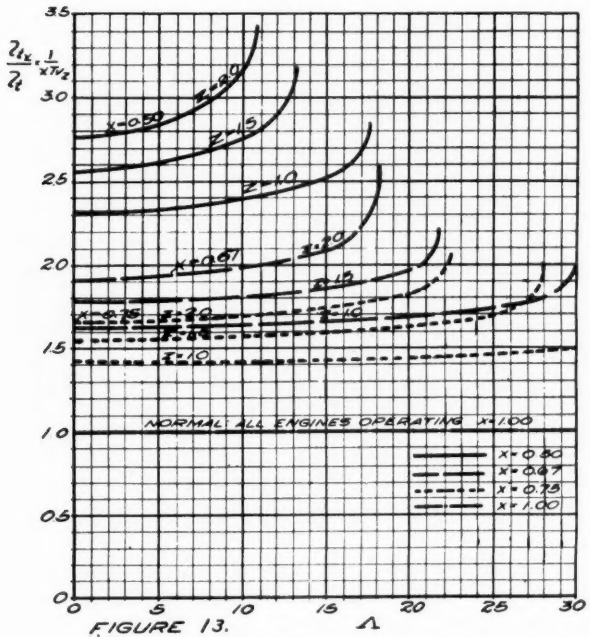


FIGURE 13.

$\frac{z_{tx}}{z_t}$ AS A FUNCTION OF PARAMETER Λ AND PARASITE DRAG RATIO Z FOR MULTI-ENGINE AIRPLANES AFTER ENGINE FAILURE.

X = RATIO OF NUMBER OF ENGINES OPERATING TO TOTAL NUMBER AVAILABLE.

Use of Charts

In using these charts the general procedure will ordinarily be as follows:—

(1) From the basic characteristics of the airplane the performance parameters l_p, l_s, l_t and Λ are obtained by equation (1), from which

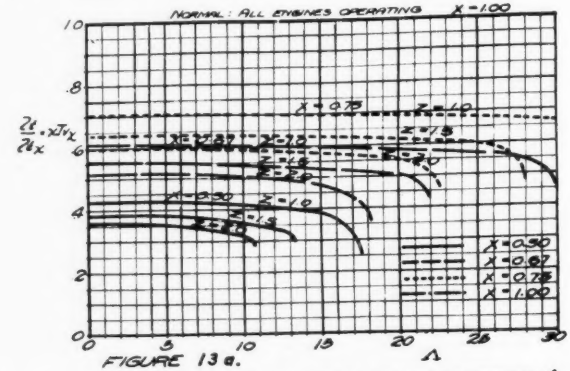


FIGURE 13a.

$\frac{l_p}{l_x} = X T_x$ AS A FUNCTION OF PARAMETER Λ AND PARASITE DRAG RATIO Z FOR MULTI-ENGINE AIRPLANES AFTER ENGINE FAILURE.

X = RATIO OF NUMBER OF ENGINES OPERATING TO TOTAL NUMBER AVAILABLE.

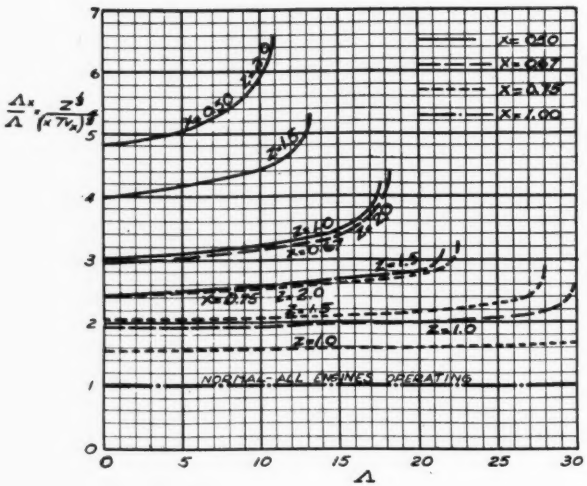


FIGURE 14.

$\frac{\Lambda_x}{\Lambda}$ AS A FUNCTION OF PARAMETER Λ AND PARASITE DRAG Z FOR MULTI-ENGINE AIRPLANES AFTER ENGINE FAILURE

X = RATIO OF NUMBER OF ENGINES OPERATING TO TOTAL NUMBER AVAILABLE

the usual performance characteristics on full power can be obtained as outlined in References 1 and 2. These must be properly modified for supercharged engines and controllable-pitch propellers. If

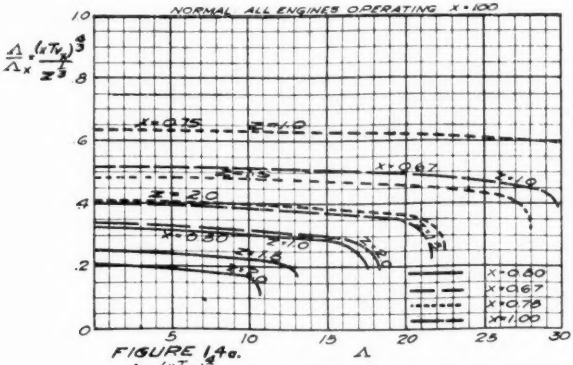


FIGURE 14a.

$\frac{\Delta}{\Lambda_x} \cdot \frac{(xT_v)^{\frac{2}{3}}}{Z^{\frac{1}{3}}}$ AS A FUNCTION OF PARAMETER Λ AND PARASITE DRAG RATIO Z FOR MULTI-ENGINE AIRPLANES AFTER ENGINE FAILURE.

X = RATIO OF NUMBER OF ENGINES OPERATING TO TOTAL NUMBER AVAILABLE.

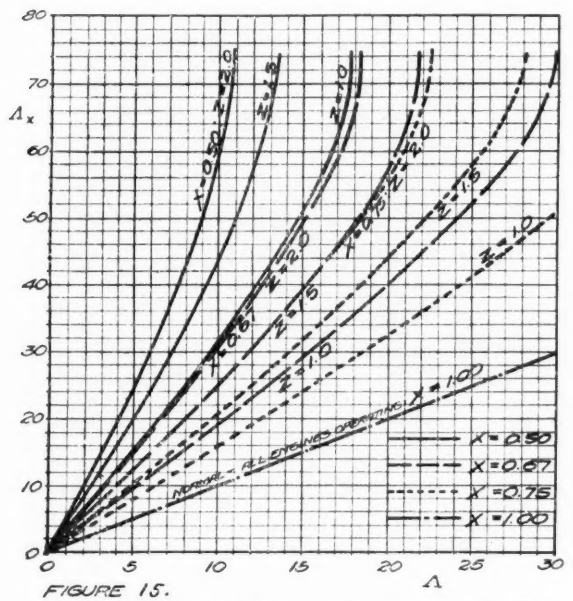


FIGURE 15.

Λ_x AS A FUNCTION OF PARAMETER Λ AND PARASITE DRAG RATIO Z FOR MULTI-ENGINE AIRPLANES AFTER ENGINE FAILURE.

X = RATIO OF NUMBER OF ENGINES OPERATING TO TOTAL NUMBER AVAILABLE

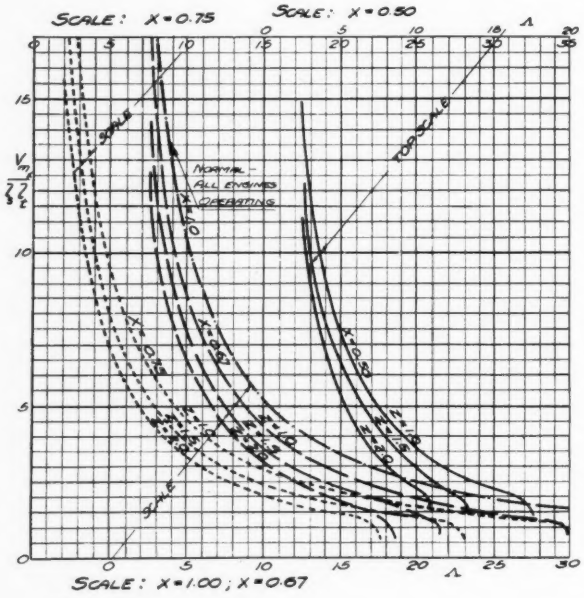


FIGURE 16.

$\frac{V_{m_x}}{\sqrt[3]{z}}$ AS A FUNCTION OF PARAMETER Λ AND PARASITE DRAG RATIO Z FOR MULTI-ENGINE AIRPLANES AFTER ENGINE FAILURE

V_{m_x} = MAXIMUM VELOCITY AT SEA LEVEL (MPH)
X = RATIO OF NUMBER OF ENGINES OPERATING TO TOTAL NUMBER AVAILABLE.

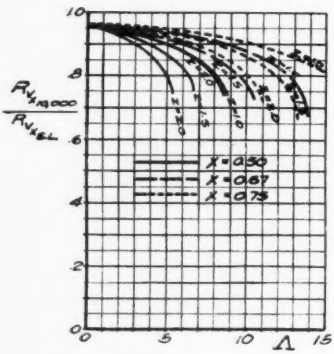


FIGURE 16a.

$\frac{R_{V_{\text{@ 10,000}}}}{R_{V_{\text{@ S.L.}}}}$ AS A FUNCTION OF PARAMETER Λ AND PARASITE DRAG RATIO Z FOR MULTI-ENGINE AIRPLANES AFTER ENGINE FAILURE.

X = RATIO OF NUMBER OF ENGINES OPERATING TO TOTAL NUMBER AVAILABLE.

performance has already been calculated or determined from flight test, Λ and l_t can be obtained from the normal full-power curves in Figs. 17 and 18.

(2) The percentage drag increases resulting from the idling propeller and additional drag of the airplane are obtained from Figs. 5 to 10, hence z is determined. Different values of z should be used for determining the various characteristics.

(3) The principal performance characteristics are found from the normal values of the parameters l_p, l_s, l_t and Λ, and z by Figs. 16, 17 and 18. Alternately, the new values of the parameters can be calculated, or obtained through Figs. 13, 14 and 15, and z. Then the charts of Reference 1 are used to obtain the performance after engine failures.

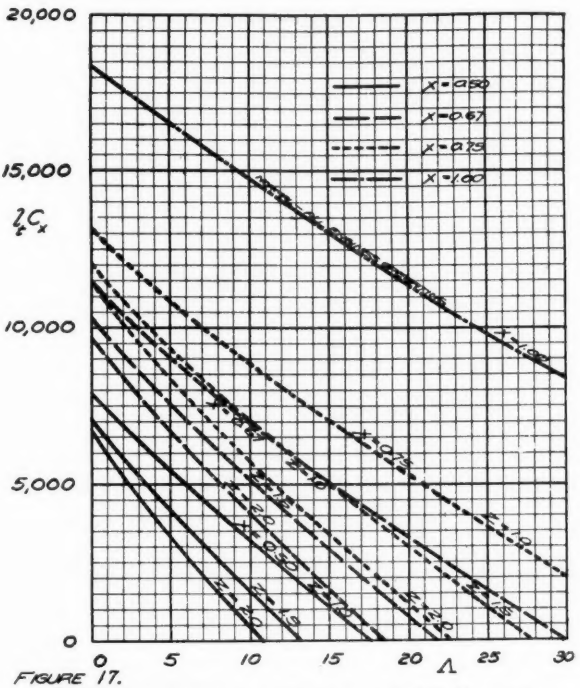


FIGURE 17.

ζC_x AS A FUNCTION OF PARAMETER Λ AND PARASITE DRAG RATIO z FOR MULTI-ENGINE AIRPLANES AFTER ENGINE FAILURE

C_x = MAXIMUM RATE OF CLIMB AT SEA LEVEL (FT/MIN)

X = RATIO OF NUMBER OF ENGINES OPERATING TO TOTAL NUMBER AVAILABLE.

AERODYNAMIC DESIGN

Achieving reliability in multi-engine airplanes is largely dependent upon the proper aerodynamic design of the airplane. It is necessary that special attention be given to the design of the airplane for flight with one or more engines out of operation. The multi-engine airplane should be definitely designed for this condition if the reliability consistent with the additional complication of many engines

is to be realised. As has been previously pointed out, safety and reliability of the multi-engine airplane are not necessarily greater than that of a single-engine airplane, unless after engine failure it is capable of completing its mission in an efficient manner with adequate control.

Certain aerodynamic features are available which enable the engineer to design a multi-engine airplane that has good performance after engine failure. The principal considerations for obtaining most favourable operation are outlined below :—

1. The rudder should produce sufficient yawing moment at the zero yaw attitude of flight to counterbalance the moments resulting from offset thrust, idling propeller drag, and any adverse yaw due to aileron action. The magnitude of this moment should be ample to provide for the lowest velocity intended for operation, usually near the stall.

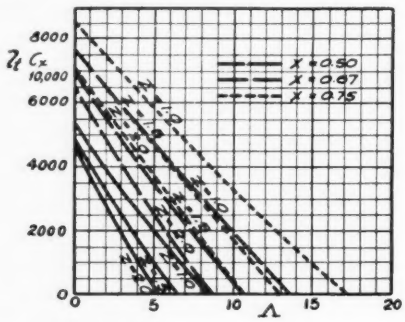


FIGURE 17a.

$\eta_t C_{x_{10,000}}$ AS A FUNCTION OF PARAMETER Λ AND PARASITE DRAG RATIO Z FOR MULTI-ENGINE AIRPLANES AFTER ENGINE FAILURE

X = RATIO OF NUMBER OF ENGINES OPERATING TO TOTAL NUMBER AVAILABLE

2. The vertical surface should be designed as an efficient lifting surface based essentially on the criteria that would be used for judging a good wing design. It should be of high aspect ratio and so disposed that the efficiency of the surface is not impaired by adverse interference effects. The rudder angle necessary for producing equilibrium should not be too large because of the high parasite drag that might result.

3. A rudder flap is needed of sufficient size to hold the rudder in the required position with zero control force. Likewise, the ailerons and elevators require trimming flaps sufficient to enable the airplane to be flown " hands off."

4. Propellers should be of the feathering type in order to reduce their drag when an engine fails. When turning against the torque of the engine, the negative drag of a propeller in high pitch is slightly less than when in low pitch. For higher pitch settings a free-wheeling propeller has considerably more drag than the feathered type, but less than when it is turning against engine torque. Reducing the propeller drag decreases the rudder size required and the drag of the rudder.

5. Span loading of the airplane should be as small as feasible (that is, large span and/or low weight) since span and weight have the greatest effect on ceiling of any of the airplane parameters. The problem of flight after engine failure is

largely one of designing an airplane that has more than the usual capabilities in absolute ceiling.

6. The general " cleanness " of design of the airplane and efficiency of all component parts must be kept at their highest possible value, since all favourable and unfavourable effects are magnified when operating after engine failure.

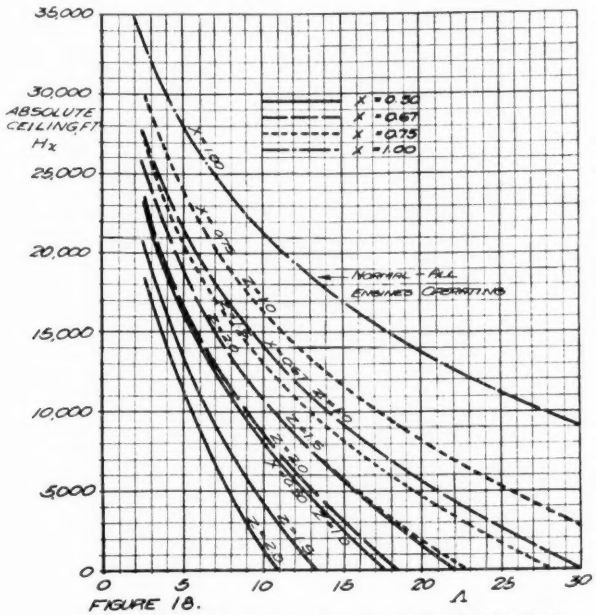


FIGURE 18.

ABSOLUTE CEILING H_x AS A FUNCTION OF PARAMETER Λ AND PARASITE DRAG RATIO Z FOR MULTI-ENGINE AIRPLANES AFTER ENGINE FAILURE.

X = RATIO OF NUMBER OF ENGINES OPERATING TO TOTAL NUMBER AVAILABLE

7. The rudder moment required for balance should be investigated at the ceiling; especially for airplanes with highly supercharged engines, because aerodynamic force would there be reduced while thrust still remained large. In fact, bi-motored airplanes with highly supercharged engines will be found to require for single-engine operation a rudder somewhat out of proportion to that which would normally be satisfactory.

All of these factors should be given due consideration if it is desired to achieve the reliability and safety factor possible when flying with one or more engines out of operation.

Example of Use of Method

In order to illustrate the application of this method and the agreement between flight test results and calculations, the Douglas DC-2 Bi-motor Transport is used as an example since complete data on it are available.

Flight test results for full gross load reduced to standard performance conditions are as follows:—

On Full Power.

High speed at 8,000ft.	213 m.p.h.
Cruising speed at 75 per cent. power at 14,000ft....	200 m.p.h.
Maximum rate of climb at 8,000ft.	1,000 ft./min.
Absolute ceiling	25,400

On Single Engine.

	Full Load.	Less 1,000lb. Fuel. (Half Normal Fuel Load).
Absolute ceiling	9,500ft.	10,800ft.
Maximum rate of climb at 6,000ft. ...	70 ft./min.	110 ft./min.

The performance on full power by reverse solution of the charts of Reference 1 yields the following performance parameters:—

$\Lambda_0 = 6.55$ (see Fig. 18, normal operation).
$l_{to} = 10.4$ (see Fig. 17, normal operation).
$f = 18.0$.

Propeller Drag

For the 1,820 cubic inch engine, geared 16:11 at 9,500ft.,

$Q_t/\text{r.p.m.}_p = 0.000057 \times 1{,}820\ (1 + 0.00002 \times 9{,}500)\ 1.2/(11/16) = 0.216$ (equation 15).

With the three-bladed 11-foot propeller at 113 miles per hour set 23° at 0.75 R. in low pitch and 32° in high pitch,

$$Q_n = (17{,}200 \times 0.216)/(0.750 \times 113 \times 11.0^4) = 0.0300 \text{ (equation 20)}.$$

Then

$T_c = -0.0136$ (Fig. 8 for two-bladed propellers) for 23° blade angle.
$= -0.0076$,, ,, ,, ,, 32° ,,

and

$f_p = 3 \times 11.0^2 \times 0.0136 = 4.9$ for 23° blade angle.
$= 3 \times 11.0^2 \times 0.0076 = 2.8$ for 32° ,,

Likewise, the drag of the propellers locked and feathered are found from Fig. 9 to be:—

	Locked.		Free-Wheeling.		Feathered.
Angle at 0.75 R.	23°	32°	23°	32°	87°
T_c	−0.00225	−0.0020	−0.0072	−0.0035	−0.0013
f_p	8.2	7.3	2.6	1.3	0.5

Additional Drag

For the offset thrust of 9.0ft. and tail length of 33ft.,

$$F = (9.0/33)\ \{\ 2 + (1 + 9.0/9.0)\ (4.9/18.0)\ \} = 0.69 \text{ at absolute ceiling},$$

and

$$\Delta f/f = 0.28 \text{ (for efficient design, Fig. 10)}.$$

Total Parasite Drag Increase Ratio

$z = 1 + (4.9/18) + 0.28 = 1.55$ 23° at 0.75 R.
$= 1 + (2.8/18) + 0.26 = 1.42$ 32° at 0.75 R.

Similarly for other cases of propeller settings,

	Locked.		Free-Wheeling.		Feathered.
Angle at 0.75 R. ...	23°	32°	23°	32°	87°
F	0.79	0.76	0.63	0.58	0.56
$\Delta f/f$	0.32	0.31	0.26	0.24	0.23
f_p/f	0.46	0.41	0.14	0.07	0.03
z	1.78	1.72	1.40	1.31	1.26

Absolute Ceiling

The absolute ceiling according to Fig. 18, for $\Lambda_0=6.55$ and $z=1.55$ is

$H_1=$ 9,500ft. with inoperative propeller in low pitch.
$=$10,500ft. ,, ,, ,, high ,,

Approximately 1,000ft. increase in ceiling is obtained by setting the idling propeller in high pitch.

For the other propeller settings, the comparative single-engine ceilings are

	Normal Engine Torque.		Locked.		Free-Wheeling.		Feathered
Angle at 0.75 R.	23°	32°	23°	32°	23°	32°	87°
Single-engine ceiling	9,500	10,500	8,400	8,700	10,500	11,100	11,500
Change in single-engine ceiling	—	+1,000	−1,100	−800	+1,000	+1,600	+2,000

By dumping 1,000lbs. of fuel, which is about half the normal fuel load, Λ_0 is increased to

$$\Lambda_0=6.55\times[17{,}000/18{,}000]^2=5.84\ (-1{,}000\text{lb.})$$

and the normal single-engine ceiling increases 1,400ft. from 9,500ft. to

$H_1=$10,900ft. (less 1,000lb. fuel with propeller at 23°).

Operation in Flight

Control of this airplane when operating on one engine was carefully studied with the result that it can be flown in this condition " hands off."

In one test a take-off was effected during which one engine was cut out after having traversed half of the take-off runway at 4,200ft. above sea level. The airplane was climbed, flown at 8,300ft. altitude, 1,000ft. above the highest point of the transcontinental air line which is 7,300ft. above sea level, and landed at the next regular airport, 5,100ft. above sea level. The entire flight was made on the remaining engine without causing any unusual strain on the pilot or airplane. It is notable that on this entire single-engine flight an average terminal-to-terminal speed of approximately 124 miles per hour was made, which practically equals that formerly obtained with tri-motored equipment.

This illustration serves to demonstrate that a high degree of safety in operation of an airplane can be achieved by thorough study and application of the various principles and problems relating to flight after engine failure.

CONCLUSION

Reliability and safety in the operation of an air line are best served by multi-engine airplanes capable of completing under good control all required flights after engine failure.

In order that the airplane be capable of developing its full potentialities in flight after engine failure it is necessary that comfortable and sufficient rudder control be provided to maintain flight at approximately zero angle of yaw. The control must be sufficient to handle emergencies such as failure just after take-off, etc.

The performance of the airplane after engine failure can be calculated by a rapid parameter and chart method. The principal parameters required are the usual parasite, span and thrust horse-power loadings, l_p, l_s and l_t respectively, the parameter $\Lambda=l_s l_t^{4/3}/l_p^{\frac{1}{3}}$, and parasite drag ratio z. Charts for finding z and the performance after engine failure are included.

The influence of the various factors affecting the performance after engine failure is readily seen. It is important that span be increased to a maximum, and that weight and propeller drag be reduced to a minimum. It is further desirable that the propeller offset from the airplane's plane of symmetry be as small as possible. The airplane should fly nearly at the attitude of zero yaw in

order that drag remain low. The vertical surface should be of efficient aerodynamic design and have low drag with the rudder deflected.

For construction of the charts, all increase in drag of the airplane has been assumed to be of the parasitic type. This assumption has been found to be consistent with available flight test data. Should it be found desirable when sufficient data are available, all variations could be determined from the general relations, and charts developed therefrom.

Careful study of the various factors involved in flight after engine failure, particularly regarding control and performance, should enable the engineer to design an airplane that has control and performance satisfactory for any reasonable requirement. For multi-engine airplanes, the performance after engine failure should be regarded as a definite problem of design.

Outside of the purely mechanical reason that very large engines are not yet available, the principal justification for the multi-engine airplane is its possibility of continuing safe and satisfactory flight after partial engine failure. The importance of the problems of performance and control involved is, therefore, directly comparable to the basic problems of normal flight.

References

1. Oswald, W. Bailey: General Formulas and Charts for the Calculation of Airplane Performance. N.A.C.A. Technical Report No. 408, 1932.
2. Oswald, W. Bailey: Methods of Performance Calculation for Airplanes with Supercharged Engines. Prepared by R. B. Ashley. Air Corps Information Circular No. 679, 1933.
3. Hartman, Edwin P.: Negative Thrust and Torque Characteristics of an Adjustable-Pitch Metal Propeller. N.A.C.A. Technical Report No. 464, 1933.

Mr. Douglas showed a film and added the following commentary:—

I consider it a great honour to be here before you to-night on such an outstanding occasion to be able to join with your Society in again honouring the memory of Wilbur Wright. I bring to the members of the Royal Aeronautical Society the hearty and cordial greetings of the Institute of Aeronautical Sciences, our younger but similar association in America. To-night I am not going to talk directly on the technical paper which I have submitted to you, but rather on the general subject of the developments in the air transport field in America. I not only feel that this might be less trying to many of you, but I am hopeful that the moving picture film I am about to have shown to you will so engross your attention that any defects in my talk will be unnoticed. As might be said in Hollywood, film by Fox, Warner and others—sound effects by Douglas!

The film to be shown is somewhat historical in that we will see at the start the first really successful air liners, namely, the early Fokker and Ford tri-engined planes. To touch but lightly on American air transport history, let me recall to you that it really started in 1926, when our Post Office Department transferred the operation of mail planes to private carriers. The revenues resulting to private concerns from this gave the needed subsidy to permit several capable concerns to embark seriously in the business of carrying passengers on regular schedules. Fokker and Ford made the first real contributions to the passenger equipment of these lines, and the records which these early air liners have to their credit is one to be proud of.

The stock market must be given some credit for the rapid increase in air travel in the early phase, since the money secured by the industry from Wall Street made possible a great expansion of facilities. In this period the development was most rapid in the ground organisation of our large air carriers and in the navigational facilities supplied, in the main, by our constructive Department of Commerce. Thus, by, we will say, 1930, and in spite of an already hesitant tone in general business in America, the stage was set for the really rapid technological progress of the past five years.

It seems to me it has been the golden age of aeronautics for us—although not an age for gold in America!—an alert and ambitious military technical personnel played its part in accelerating the use of brains by our designers. A growing competition among our air lines spurred the development of faster and safer air liners. A need on the part of the manufacturers for a broader market for their products and an ability, represented in favourable balance sheets, to seek this with newer and better types, both military and civilian, added to the activity of this field. Early attempts at really fast airplanes, such as the original and successful Lockheed, pointed the way to others as to what might be done. But even beyond all this, and most certainly marking the time as one of real accomplishment, has been the fact that all agencies concerned in and contributing to aviation have been most alert, co-operative and constructive. Our engines have been developing at a pace to permit the airplane designer to raise his sights from time to time. Our instrument and radio people have aided tremendously by furnishing us with the means to fly in bad weather. Propeller makers have been most helpful and, in fact, I can say that the development of the variable pitch propeller to the practical point it has reached to-day, is probably the most fundamentally important development of this period. Without it many of our present air liners would be impracticable.

As the first modern multi-engine air liner development of this golden age we see on the screen the Boeing. This excellent ship with its high speed, twin instead of three engines, with its ability to continue flight on only one engine, was the first really modern transport. United Air Lines made use of these airplanes and was immediately successful in stimulating air travel. The public was offered flight schedules across our continent that attracted business on the basis of comfort, safety and speed. Other air lines were forced to seek new equipment and to try to still further increase speed and comfort. T. & W.A. embarked on an ambitious development programme, enlisting the Douglas Company in the project. The result was our DC2 type, which most of you have undoubtedly seen flying in and out of Croydon and which you will also see over some of our western mountainous country in the film. We of the Douglas Company are proud of this airplane, but we concede that we were but one agency in its development. From its inception we had the most excellent and wholehearted aid from the air lines. Pilots and maintenance engineers gave of their time and knowledge. The thought was developed that speed in the air was but one function to be solved in the solution of the equation of a successful ship. Speed of inspection and maintenance during fuelling stops, and studies to cut the time required to make replacements, were given great consideration. Safety was a factor which, of course, had to be developed to the utmost possible. Here we were furnished aid by the engine maker, the instrument people, the propeller designers and the wind tunnel and research agencies of our government and of our technical institutions. Flying, as our major air lines do, over great distances across high country in many places and through or over weather of the worst at times and continuation of flight at any point with one of our two engines stopped, was the prime requisite we had always before us in our design. As developed, the DC2 actually took off after cutting one engine at a point 40 per cent. of the take-off run from a field about 4,500ft. high, climbed on up to about 8,500ft. and completed its flight across the highest part of the air line, some 300 miles, and all with full load.

Comfort was studied with care, and sound engineers developed efficient and practical methods of eliminating the formerly disagreeable and tiring noise of air transport. Heating and ventilation comparable to that found in modern buildings was effected after the aid of related industries was obtained.

The film also gives you a view of other interesting and remarkable achievements in American civil aviation. The Lockheed Electra has been built for and is being used very successfully by some of the air lines needing a smaller capacity

airplane than the DC2. The Lockheed has speed, comfort, and safety that are now demanded by our air travellers. An equally interesting and worth while air liner is the Curtiss Sleeper. You will see on the screen a rather interesting view of the interior showing the comfortable quarters and a fair passenger turning in for a good sleep while en route over the American desert. I have had the surprising experience of seeing a mother settle her small family of two children, aged 2 and 4, for a quiet sleep at 10,000ft. with the greatest of nonchalance. I felt at that moment that air transportation was really here and was spurred to plan more comfortable and roomy night quarters and facilities for our next developments.

I have spoken only about land transportation. The film will show you flying views of the latest and finest of our flying boats—the Sikorsky and Martin. These have been brought out by those two great concerns working closely with Pan-American Airways. They, in the Ford-Fokker era of land plane transportation, started their ambitious and highly successful foreign air lines with flying boats largely developed from naval boats. These latest pieces of equipment represent the last word as we know it in America for the safe and successful operation of overseas transport. With their four great engines it is difficult to imagine a flight failure due to engine trouble. Seaworthy hulls of large size seem adequate to permit of safe landings under all conditions likely to be met. Comfort is even better served in these commodious hulls than in the smaller bodies of our land planes.

The development of our modern air liner technically from 1926 to 1935 is quite apparent to the eye of the engineer. The development of the traffic in America that has spurred this on is revealed by a few statistics. In 1926 the total of commercial flying was about 4,000,000 plane-miles, a plane-mile being the equivalent of one plane flying one mile, whilst in 1934 this amounted to 41,000,000 plane-miles, a tenfold increase. The number of passengers carried increased from less than 6,000 in 1926 to 460,000 in 1934. Air mail volume increased from slightly over 200,000lbs. in 1926 to an annual rate of 10,000,000lbs. in the last quarter of 1934. Air express, an as yet practically undeveloped source of revenue, increased from 3,500lbs. to 2,000,000lbs. in this period. The time of flight from coast to coast of America has shown a great betterment in the past nine years, being now 16 hours against about 48 hours in 1926.

That we have achieved a marked gain in safety is proved by the records which show that whilst there was one fatality per 897,000 miles of air line operation in 1926, there was only one death for 6,817,000 miles in 1934. This improvement is most significant when consideration is given to the fact that we are now flying a great deal at night, which was not the case nine years ago and, furthermore, we are now operating in weather which even two years ago we would have regarded as impossible.

The story of the development of modern air liners would not be complete if we did not give credit to the effect of greater technical thought as applied to the flight of the air liner, rather than just to the design of the machines. Formerly the aeronautical engineer had completed his work when the final flight tests of his airplane were completed. From then on it was up to the pilot who, whilst vitally concerned with the proper speed and altitude at which to fly, was not informed completely as to just what factors determined his best course. With the idea of realising the ultimate in air line operations from the standpoint of speed and economy, many engineers and engineering pilots have necessarily collaborated. Results of their work in theory and flight tests have been made available to all and in such form that they are of great practical value and aid. Dr. Osborn, of our staff, and Pilot Eddie Allen have blazed the path along these lines, and further valuable information is being gathered by others inspired by this work. As can be seen from what I have said, we are only just learning to utilise the machine that we have developed. This brings me to the thought of

the future development and I believe we should think for a moment at least of this. What lines do we wish to develop along; speed, safety, comfort, size, efficiency? Speed to its ultimate, most certainly. Speed is the first thing that the air line ticket man has for a selling point. There may be many who fly on an air liner for the thrill or the change as compared with surface travel, but these will be fewer each year. There are undoubtedly many, and always will be, who fly because they prefer air travel on the grounds of cleanliness and lack of vibration, but speed must always be the greatest reason for travelling by air. Future development, therefore, must include the development of all the speed possibilities in air travel consistent with other necessary considerations. What the limit is, I cannot say. The aerodynamic engineer will, with some hesitancy, place a limit, but no one can be sure of it. I believe we should be cruising at 300 miles per hour in another ten years. I cannot say how; if I could we would be doing it now. Stratosphere or sub-stratosphere flight, while not to be developed necessarily primarily for speed, may open up avenues of development now not clear to us. Better utilisation of slow landing devices will undoubtedly give us our next measurable increase in practical cruising speeds. There is undoubtedly some room for increases in overall aerodynamic efficiency. Possibly some expectations of somewhat better propulsive efficiencies is sound.

What of the development towards more safety? We must admit that whilst great strides have been made in this direction, more can be and must be done. We can reasonably expect to continue to improve the reliability of our engines, our instruments, our radio, our plumbing, and other vital gadgets, but at the moment we can only visualise a general betterment in the airplane itself by such changes as four-engined transport capable of flying on any two engines, rather than twin-engine airplanes. It seems at the moment that the most important advance in safety that we should be concerned in is in better protection against icing up, against electrical storms and in better development of blind flying and blind landing facilities. The icing problem is partially but inadequately solved at the moment. Its better solution may be mechanical and may also be along the line of greater altitude capabilities of the air liner. Hand in hand with this solution for icing goes the possibility that protection against dangerous electrical conditions may lie mainly in high altitude flight. Comfort development certainly is an open field and takes in the problem not only of comfort but sustentation of life at the high altitude that we may soon wish to fly at. Pressure cabins and/or free oxygen in the cabins are both being experimented with to-day. Our air lines are working diligently with our designers on these points and we look with confidence to some solution soon.

Our future developments from the standpoint of size seem, except in the case of trans-oceanic flying boats, to be controlled by traffic and comfort. Intrinsically, one of the advantages of air transport is its flexibility, so it would seem that size, beyond an efficient point from a structural standpoint and an economic one, is not to be expected to show any great change. Efficiency we must certainly hope to continue to improve, for air transport to be able to show an operating profit without depending on any subsidy. This will be improved by better pay-load percentages, lower first costs and lower maintenance charges. Already in America we find the operating costs of the modern ships quite markedly lower than the older and slower planes. Therefore, we need not fear that even with our speed development we shall cease decreasing costs.

Might I say that it seems to me that aviation is so tied with ground facilities of such a world-wide and international scope that the most important developments will come when we find means to more completely co-operate as nations. Also it appears that so much time and money is wasted because of the duplication of the same experiments in different countries, that something constructive should be considered at the present time. From this point of view military aviation seems to be a deterrent factor on more rapid and less costly progress. Why,

however, can we not hope to take certain general aviation problems that do not involve anything intrinsically military, and allot them among the major nations; certain problems to one nation with more experience on a certain phase and certain problems to another? A complete interchange of the knowledge resulting would then follow. Surely this is possible, and if it is, the aviation industry, instead of being a potential breeder of war with its increasingly dangerous weapon, might become an agent in spreading understanding. I offer these last thoughts humbly and in the belief that engineers and scientists such as form the membership of the Royal Aeronautical Society, are able most fully to grasp the possibilities. A glorious future lies before aviation. Its development has only just commenced. May I hope that those interested in it here will believe that we in America extend to you our fellowship and promise of full co-operation for the common good.

The PRESIDENT: In asking Mr. Fairey to propose a vote of thanks to Mr. Douglas, he said that Mr. Douglas was indeed a remarkable man because he had given them three kinds of entertainment. First of all there was the scientific paper which they were all going to read in bed; then there was the film which they really ought to see again; and finally, there were the comments which Mr. Douglas had made in giving that film. In his quiet way Mr. Douglas had said many things in his talk which must not be lost, and therefore he was going to ask him to allow the Society to print his talk in the Journal separately from the lecture, which had already been printed, because personally he felt that was very necessary.

Mr. C. R. FAIREY (*Past-President*): They had listened to a very vivid, practical and interesting talk, but they all had in their hands the print of an equally interesting and even more important lecture, since in it Mr. Douglas proved that high speed in aviation could be obtained without any loss of economy, of safety, or of comfort, as the aircraft on the world's airways had already proved. It was to be hoped that in the hands of our designers this lecture would have some effects on the future of British air transport. If it led to the fact that we never heard again of that strange doctrine under the headline of " the fallacy of speed," it would have done something, although he was never quite clear himself as to whether the protagonists of that amazing doctrine were out to prove that aeroplanes ought not to go fast or to apologise because they did not do so. After all the basic ratio for aeronautical engineers, L/D, had a commercial as well as a technical significance. L was the income and D represented the outgoings, and anything we could do to improve L/D was all to the good of commercial aviation, and Mr. Douglas had certainly done that.

Everybody was grateful to Mr. Douglas for having travelled the long distance he had to deliver this lecture and also for the trouble he had taken in preparing it, and further, for giving them the opportunity of meeting him personally.

The vote of thanks was carried with hearty enthusiasm.

Mr. DOUGLAS, in acknowledging the vote of thanks, said the pleasure he had in coming to England to give this lecture had been enhanced by the great kindness shown to him and the indication that had been given that those who had listened to him had, at any rate, enjoyed the lecture to some extent.

A RESEARCH INTO TESTS FOR MATERIALS USED IN COLD PRESSING OPERATIONS, WITH SPECIAL REFERENCE TO THE FLUID-PRESSURE CUPPING TEST *

BY

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The rapidly extending employment in many industries of cold pressing and stamping operations in the production from sheet metal of a great variety of components, embracing both simple and very complex shapes, renders cold pressing an extremely suitable subject at the present time for a joint discussion by a group of technical societies representing a wide range of industries. The particular interests of these industries naturally vary widely, both as regards type of production and the materials employed, but there should exist many basic problems common to all. Reviewing the subject broadly, it appears probable that these problems could be conveniently discussed under the following general headings:—

1. Problems associated with Manufacture of Sheet Metal.
2. Metallurgical Problems.
3. Devisement of suitable Mechanical Tests.
4. Die-Design.
5. General Mechanics of Plastic Flow of Metals.

The notes contributed by Dr. C. H. Desch and Professor G. Sachs will, no doubt, open up very interesting discussions on sections 2 and 5 respectively, while much valuable information regarding sections 1 and 4 should be forthcoming from those engaged in these difficult and exceedingly interesting aspects of the general subject of cold pressing.

The present paper is restricted entirely to an examination of some of the mechanical tests which are often employed for sheet metal, while particular attention is given to the investigation and development of a form of cupping test which is comparatively new. The collection of experiences and views regarding adequate methods of specifying and testing the suitability of a given sheet material for a given pressing operation will, it is hoped, prove to be one of the fruitful results of the general discussion, for the position of this important aspect at the present time is somewhat curious and certainly unsatisfactory. A few prefatory remarks on this position may not be out of place. In most branches of engineering construction, the result of general and service experience has enabled the engineer to specify the essential desirable properties associated with a suitable material, and in many cases to recognise other properties which are undesirable. It thus becomes possible to specify a few very simple tests which, although often quite unrelated to the service conditions imposed on the finished article, yet sort out suitable from unsuitable materials in a manner which is sufficiently satisfactory. That this happy position does not yet also apply to materials for cold pressing operations is probably partly, at least, due to the following essential difference:

* A paper read at a joint meeting of the Institution of Automobile Engineers, the Royal Aeronautical Society and certain other Technical Institutions and Societies.

† Superintendent, Engineering Dept., National Physical Laboratory.

‡ Senior Scientific Officer, Engineering Dept., National Physical Laboratory.

that, whereas in ordinary construction, design relates primarily to *elastic* conditions, it is the *plastic* properties of metals which are of major importance during cold pressing operations. This latter fact is of the greatest importance and reacts on the problem in many ways. For example, a material which has proved entirely satisfactory for one type of pressing may fail in the production of another type of different *form*. Then, again, a clearly defined " yield " point—generally a desirable characteristic for engineering materials—is accepted as being directly responsible for the production of " stretcher strains " in a pressing (where the *amount* of imposed plastic strain varies from position to position). Another characteristic of metals which assumes great importance in the present connection is that of " strain-hardening," following plastic deformation, which is rendered difficult to cater for owing to the *time* element involved in this recovery, wholly or partial, of elasticity; the period involved is a function of the amount of previous plastic strain. The operation of cold-rolling, either in the works of the steel maker or the user, will thus result in the " breaking-down " of the yield point, and usually an increase in the tensile strength. The first result is, however, of a transitory nature. Given sufficient time for " recovery," an increased value of the yield point results, which in many cases represents an undesirable feature of the metal sheet, although the rolling may have been necessary to attain a desired strength or surface finish. An ideal condition for a pressing steel would no doubt be one corresponding to a tensile stress-strain curve which is of a " smooth " nature throughout, entirely free from sudden changes in curvature. It is important to note that it should possess this characteristic *immediately before entering the press*. The recognition of this fact has led to the works practice of " roller levelling " the metal before pressing. In this way, sufficient plastic deformation is caused by the imposed bending actions to produce the desired condition without unduly affecting the total ductility or thickness of the sheet.

Considering sheet steel destined for deep drawing purposes, the properties and suitability of the sheet are naturally intimately dependent on the processes used by the steel maker, including the hot-rolling, heat-treatments, cold-rolling, etc. Hence it may not be a matter for great surprise that the provision of a suitable material is often left almost entirely by the user to the steel maker. In fact, in several industries, it appears to be the practice to purchase material for a given product without specifying any acceptance test whatever, on the understanding that the material will be accepted provided the " scrap " in the pressing shop does not exceed a stated percentage. To prevent misapprehension, it must be added that in such cases the steel maker and user usually work in the closest co-operation during the pressing stage so that the choice of a material really represents the combined experience and judgment of both parties concerned. Nevertheless, testing at the works of the user is often practically non-existent, except, possibly, in the subsequent examination of material which has proved unsatisfactory in operation. However, it *should* be possible to specify in advance a desirable material, provided the characteristics of the available materials have been sufficiently studied on correct lines, and provided also that the problem is not complicated by the factor of unsuitable die-design. A certain measure of agreement appears, in fact, to exist regarding suitable chemical compositions, forms of micro-structure, and grain size. Among mechanical tests, the tensile test is generally favoured as being the most informative, particularly with regard to the evidence of " ductility " afforded by the value of " elongation " (especially the " general " elongation); the use of some form of hardness indentation test is probably chiefly of value as giving a result capable of relation with the tensile strength. In addition, some standard form of " cupping " test, in which an indenting tool is used, such as the Erichsen, Olsen, etc., is often employed, but appears to be regarded as of a " confirmatory " nature only, not so discriminating, with regard to drawing properties, as the tensile test. This type of test has been described as capable of indicating immediately a steel which is quite unsuitable, but affording no means of distinguishing between those steels which

are moderately good for pressing purposes and others which are perfectly satisfactory. Also this form of cupping test is of use in affording information regarding the probable surface appearance of a finished pressing, this being related to the grain size of the metal.

The essential features of the most widely employed forms of cupping test may be briefly summarised. A square or circular piece of sheet metal is held between annular steel jaws, and the rounded end of a steel plunger or a steel ball is pressed against one face of the sheet, the other face of the sheet being unsupported, as shown in Fig. 1. A cup or depression is thus formed in the metal,

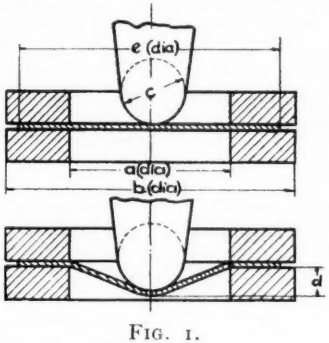

FIG. 1.

	a	b	c	e
Erichsen	27 ...	...	20 ...	
Avery	27 ...	...	20 ...	
Standard German Test ...	Various ...	...	...	
Olsen	Various ...	...	...	
Persoz	50 ...	125 ...	20 ...	100
Amsler	50 ...	...	20 ...	
Guillery	50 ...	...	20 ...	
Standard French Test	50 ...	90 ...	20 ...	90

All dimensions are expressed in millimetres.

the deformation being continuously increased until failure occurs by cracking of the sheet. The depth of the cup at failure is usually taken as the measure of the " ductility " or " workability " of the test material. Dimensions used in various forms of the test are indicated in Fig. 1. The Erichsen, Guillery, Olsen, Amsler, and Avery machines apply this form of test; in the Guillery and Olsen machines the load at which failure occurs can be observed in addition to the depth of the cup. A test of this type has the advantage that it can be carried out in a comparatively small machine, sometimes operated by hand, while no special machining or other preparation of test specimen is required. It is a matter for some surprise that cupping tests of the type referred to have not proved more useful in relation to cold pressing than appears to be the case. This may be partly due to the complex and uncertain conditions set up in the region of contact of the test specimen and the distending tool. Then, again, the uncertain amount of friction in the contact region, the difficulty of controlling the amount of slipping of the specimen in the grips, and some uncertainty in determining the precise stage at which failure first occurs, may be contributory factors. Nevertheless, the essential feature of this type of test—plastic deformation in the plane of the metal sheet—is so akin to the requirements of sheet metal during a pressing operation that, provided the *undesirable* features associated with a distending tool could be eliminated, it should be possible to devise a test method likely to be very informative. Such a test might, indeed, prove to be superior to the tensile test, inasmuch that extension of the specimen would, as in practice, occur in *all* directions, whereas any *single* tensile test obviously furnishes data relating

principally to one direction only in the sheet. The investigation to be described arose from a consideration of the above arguments and the publication* of the description of a new form of test devised by M. Jovignot. In this test the specimen is firmly clamped in annular steel grips and is deformed, by fluid pressure applied to one side of the sheet, into a dome. Rupture finally occurs as the result of the pressure and deformation; the height of the dome and fluid pressure at fracture are observed. Assuming that the deformed sheet takes the shape of a spherical segment, the stress at fracture can be approximately estimated using the usual formula for the strength of a thin spherical shell. A measure of the "ductility" of the specimen, in terms of the increase of surface area, can be deduced from the original and final dimensions of the deformed sheet. Jovignot published a few data obtained from tests on white metal sheet of various thicknesses, pointing out that the "ductility" figures obtained in his test did not bear the same relation to each other as those obtained from the same materials tested in a cupping machine of the usual type where a distending tool was employed.

The new test method appeared to be distinctly promising, and it was decided to carry out an investigation at the National Physical Laboratory with the object of arriving at some general conclusion regarding the value of the fluid pressure cupping test as a general inspection test for sheet metals; also, as far as possible, of its value as an indicator of the probable behaviour of metals in cold pressing operations. It was recognised that the success of the latter would depend largely on the number of available materials which had proved unsatisfactory in practical pressing operations; in actual fact, the number of such materials which were eventually obtained has not enabled a sufficiently wide investigation to be yet made on which a fully considered opinion can be offered. In addition to the fluid-pressure cupping tests made on a variety of materials, cupping tests of the more standard types have been carried out for comparative purposes in addition to the usual tensile tests, etc.†

Although a considerable amount of testing has been carried out, this does not, in the opinion of the authors, constitute a sufficiently complete examination of the possibilities of the fluid-pressure cupping test. The attitude adopted in offering the report is, therefore, as follows:—A new form of cupping test has been generally, *not* fully, explored; it appears to possess some advantages which may be of service to industry as a practical and simple test. The results are now reported with a view to eliciting comment and criticisms from Industry. Should these remarks generally indicate that further study of the test is desirable, such further exploration could be taken up by Industry or others directly interested; alternatively, the National Physical Laboratory might be prepared to proceed with the investigation. The latter course could, however, only be considered, provided the Industry was prepared to afford close co-operation, as it is essential that further work should be made mainly with materials whose performance in actual cold pressing operations is accurately known.

I. Materials Used in Investigation

The materials which have been examined fall into three groups as follows:—

(*a*) *Miscellaneous Commercial-Grade Materials from Stock.*

These were used mainly for general preliminary purposes and have no special significance with regard to cold pressing.

* "Method and Testing Apparatus to Determine the Extension and Breaking Load of Sheet Metals," C. Jovignot. Comptes Rendus, Vol. 190, 1930, p. 1299.

† Note.—Additional information is available concerning the composition, method of manufacture, and other test data relating to some of the materials reported on. This has not been included as it was considered desirable to concentrate the report and discussion on the main essential, namely, the general possibilities of the fluid-pressure cupping test in relation to the testing of sheet metal.

TABLE 1.

List of Materials and Tensile Test Results.†
All Test Pieces ½in. Wide and 2in. Gauge Length.

N.P.L. Identification Mark.	Material.	Thickness, in.	Yield stress, tons per sq. in.	Ultimate stress, tons per sq. in.	Elongation on 2in. per cent.	Group No. (see text).
FPW 1	Brass	0.018	15.2	20.6*	>24*	
FPW 2	Copper	0.016	—	14.3*	>21*	
GDR 2	Copper	0.039	—	15.1*	38*	
GDR 1	Copper	0.064	—	16.5*	37*	
FPW 4	Tinned iron	0.017	16.5	22.9*	17*	
FPW 5	Tinned iron	0.026	15.0	20.7*	13*	
FPW 6	Sheet iron	0.023	11.4	18.9*	21*	(*a*)
GDK	Planished steel	0.048	20.8	24.8*	11*	
GDS	Planished steel	0.063	17.6	24.4*	24*	
DDC 2	Aircraft steel	0.013	—	75	—	
DDC 3	Aircraft steel	0.010	—	74.5	—	
DVX	Aircraft steel	0.0225	—	86	5	
DVY	Aircraft steel	0.0225	—	89	5.5	
FVN 1	Mild steel	0.040	13.5	21.5*	39*	
FVN 2	Mild steel	0.040	13.5	21.4*	38*	
FWN 1	Mild steel	0.038	16.5	25.9*	27.5*	
FWN 2	Mild steel	0.041	12.3	21.3*	35.5*	
FVO 1 & 2	Cupro-nickel coated mild steel	0.032	12.3	20.8	36	(*b*)
FBO 3 & 4		0.032	14.1	21.4	34	
FVO 5		0.033	13.8	22.0	36	
FVO 6		0.034	16.1	23.9	33	
FVO 7		0.034	14.7	23.3	34	
HBI 1	Stainless steel as received	0.064	47.8	57.9	28.5	
HBI 2	Stainless steel annealed	0.066	20.0	40.3	35	
FVM 1	Zinc	0.100	—	10.5	44	
FVM 2	Zinc	0.060	—	8.3	59	
FVM 3	Zinc	0.020	—	9.2	>19	
FVM 4	Zinc	0.010	—	8.0	>17	
FWA 1, 2, 3	Soft aluminium	0.079	—	6.2	36	
FWA 4, 5, 6	Soft aluminium	0.036	—	5.9	>14	
FWA 7, 8, 9	Soft aluminium	0.019	—	5.8	>12.5	
FWA 10, 11, 12	Soft aluminium	0.010	—	6.0	>11.5	
FWA 13, 14, 15	Soft aluminium	0.005	—	5.5	>11	
FVZ 1 & 25	70/30 Brass, soft	0.060	—	21.8	70	
FVZ 2	,, ,, hard	0.060	—	42.8	7	
FVZ 3 & 26	,, ,, soft	0.040	—	21.5	66 5	
FVZ 4	,, ,, hard	0.040	—	41.8	2	
FVZ 5	,, ,, soft	0.020	—	22.5	63	
FVZ 6	,, ,, hard	0.020	—	38.3	0	
FVZ 7 & 27	,, ,, soft	0.010	—	21.4	52	(*c*)
FVZ 8	,, ,, hard	0.010	—	38.1	0	
FVZ 9	80/20 Cup. Ni, soft	0.060	—	21.0	43	
FVZ 10	,, ,, hard	0.060	—	34.5	4.5	
FVZ 11	,, ,, soft	0.040	—	21.9	41	
FVZ 12	,, ,, hard	0.040	—	36.3	4	
FVZ 13	,, ,, soft	0.020	—	22.2	36	
FVZ 14	,, ,, hard	0.020	—	32.4	2	
FVZ 15	,, ,, soft	0.010	—	22.5	31	
FVZ 16	,, ,, hard	0.010	—	33.7	0	
FVZ 17 & 28	H.C. Copper, soft	0.060	—	15.8	47	
FVZ 18	,, ,, hard	0.060	—	24.6	3	
FVZ 19 & 29	,, ,, soft	0.040	—	15.9	44.5	
FVZ 20	,, ,, hard	0.040	—	25.4	3.5	
FVZ 21	,, ,, soft	0.020	—	14.5	35.5	
FVZ 22	,, ,, hard	0.020	—	26.6	2	
FVZ 23 & 30	,, ,, soft	0.010	—	15.4	8	
FVZ 24	,, ,, hard	0.010	—	24.3	0	

* Mean of two directions at right angles.
All other N.P.L. results are the mean of at least two tests in direction of rolling.
† Tensile test results on FVZ materials taken from paper by Cook and Larke.

(*b*) *Materials Specially Obtained from Industry in View of their Known Performance in Practical Cold Pressing Operations.*

It was hoped to obtain a much greater selection than was actually received of materials of this group. Supplies were invited of materials which had given distinctly poor performance in cold pressing; also, for purposes of comparative tests, companion supplies were requested of materials generally similar, but whose practical performance had been entirely satisfactory. It will be appreciated that, for a correct assessment of the value of any mechanical test, it was essential for such companion sets to be available, rather than a miscellaneous and unrelated collection of materials, but, apparently, this request was difficult to satisfy; the supply received was disappointingly small.

(*c*) *Variety of Non-Ferrous* Sheet Metals which Fairly Represent those Used for Drawing and Pressing Operations.*

Three excellent batches were received. Those of zinc and soft aluminium each represented material of the same manufacture and treatment, in various thicknesses. The third batch, consisting of 70/30 brass, 80/20 cupro-nickel and H.C. copper, represented, for each material, four gauges each in two temper conditions; these materials are further supplies of the same materials whose physical properties have been extensively reported elsewhere† by Cook and Larke.

Particulars of the materials used are recorded in Table I, together with the results of tensile tests. The latter were made on specimens of $\frac{1}{2}$in. width, of the form since standardised‡ by the British Standards Institution. In nearly every case tests were made in duplicate, the length of the test piece being in the direction of rolling of the sheet or strip; where practicable, additional tests were also made on specimens whose axes were perpendicular to the direction of rolling of the sheet.

II. Experimental Examination of Fluid-Pressure Cupping Tests

(*a*) *The Jovignot Fluid-Pressure Cupping Test.*

In the original testing machine designed by Jovignot§ the sheet under test is placed between two annular jaws and clamped tightly by means of a screw

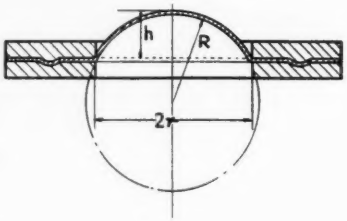

Fig. 2.

press. A reservoir full of liquid, below the test piece, is in communication with a pump of the screw type. When pressure is applied by means of this pump the test piece is forced upwards into a dome, as shown in Fig. 2. A gauge is fitted to the pump to measure the pressure, while the height of the cup is measured by a dial indicator whose point rests on the upper surface of the test piece at its

* A similar supply of *ferrous* materials was not made available.

† "Physical Testing of Copper and Copper-Rich Alloys in the Form of Thin Strip," M. Cook and E. C. Larke. Jour. Inst. Met., No. 2, 1931. Vol. XLVI., p. 245.

‡ B.S.S. No. 485, 1934. "Tests on Thin Metal Sheet and Strip."

§ *Loc. cit.*

centre. The test is continued until fracture occurs, as shown by a rapid fall of the pressure gauge pointer and, in general, also by the ejection of oil at the point of fracture. The maximum pressure and maximum height of cup are recorded. Jovignot expresses a measure of " ductility " by a " cupping coefficient " equivalent to the average increase of surface area of the test piece per unit area, thus :—

$$\text{Cupping coefficient} = h^2/r^2,$$

where h = height of cup at fracture,
r = radius of jaws.

Assuming that the deformed dome is spherical, the stress in the material at fracture may be estimated using the thin sphere formula :—

$$\text{Stress} = PR/2t,$$

where P = pressure of fluid,
t = thickness of test piece,
R = radius of curvature of spherical surface $= (r^2 + h^2)/2h$.

A commercial form of the Jovignot machine is now produced by the Société des Etablissements Malicet et Blin, which has provided its standard Guillery cupping testing machine with fittings to carry out this type of test. In this machine a pump supplies oil to the underside of a large piston to the head of which (for the Guillery or similar type of test) is normally fixed the distending tool, which is thus pressed into the sheet of metal under test. The metal is held between two serrated annular dies, and the height of the cup produced is measured by the movement of the piston. In adapting this machine for the Jovignot test the tool is replaced by a cup leather held in position by a steel plate and forming an oil-tight joint with the walls of the smaller cylinder just below the clamping dies. This smaller cylinder is filled with oil before inserting the test piece. Using the known diameters of the small and large oil cylinders, the pressure in the upper cylinder can be estimated from the reading of the gauge fitted to the large lower cylinder. A height-measuring device is fitted to the head of the machine, consisting of a rod resting on the test sheet and guided vertically, together with a multiplying lever moving over a graduated scale.

A Guillery machine of the type described (Model R2) had been ordered from the makers by the British Non-Ferrous Metals Research Association. Dr. Hutton —at that time Director of Research of the B.N.F.M.R.A.—on hearing of the proposed investigation, very kindly placed this machine at the disposal of the authors. The diameter of the die supplied with the machine was 50 mm. ; the majority of the tests have been made using this die. In addition, dies of 40 mm. and 60 mm. dia. were prepared at the N.P.L. and used in a few tests carried out to examine the influence of the die diameter. The makers of the machine pointed out that difficulties would be encountered in preserving an oil-tight joint ; these were encountered and overcome. It was also found necessary to replace the gauge with one of a more accurate type and to make various other amendments to the machine as delivered ; these presented no great difficulty and need not be described in detail. The most serious disadvantage of the machine is the restriction imposed on the gauge and strength of sheet materials which can be tested, owing to the maximum permissible oil pressure being about 1 ton per sq. in. Many of the available materials could not, on this account, be tested in the Guillery* machine ; this led the authors to devise the special machine described later.

A few exploratory tests of a general nature were made. As the use of the thin sphere formula for calculating the breaking stress is only justified if the shape of the deformed metal sheet does in fact approach a spherical surface, a few measurements were made on test pieces pressed out in the machine, but not

* In addition to the Jovignot test, three of the ordinary forms of cupping test, using a distending tool, can be made in the Guillery machine. These are the " Guillery," " A.E.G.," and " K.W.I." cupping tests, of which a brief description is given later.

taken up to their bursting point, to determine whether this assumption was approximately correct. These measurements showed that the actual shape of the domes conformed very closely to a spherical cap.

To examine the variation of thickness of metal present in a deformed sheet, a few specimens of brass were measured at various positions on the surface, using a ball-pointed micrometer. A typical set of measurements thus obtained is shown in Fig. 3. It will be seen that the thickness decreases from the edge of

FIG. 3.

Jovignot test on brass 0.018*in. thick.*
Measurements of thickness of dome (inches).

the clamping dies to the point of fracture in the centre of the dome. Neglecting local contraction, these readings demonstrate the constraint due to the clamping which has a very appreciable effect on the deformation. This suggests that a " scale effect " would be expected to become noticeable if sheet of a constant gauge were tested with various sizes of die, the ductility value probably being affected to a greater extent than the estimated stress at fracture. This point will be referred to later.

The results of the fluid-pressure test using the Guillery machine are reported in Table II. Each result represents the mean of at least two tests. A large proportion of the available materials could not be tested in this machine, owing to the restriction on the maximum permissible pressure (1 ton per sq. in.). Thus, for a material having a tensile strength of 20 tons per sq. in., the greatest thickness which can be tested on a normal die diameter of 50 mm. is about 0.03in., while for high tensile materials like aircraft steels, the maximum thickness is about 0.01in.

As shown in Table II, a few materials were each tested, using three diameters of die, viz., 40, 50 and 60 mm., in order to obtain some information regarding the influence of this variable on the measure of ductility afforded by the fluid pressure type of test. Before examining the results in detail, the general case may be briefly considered.

The preliminary experiments referred to previously had elicited two general facts, the valuable feature of the test that the deformed metal apparently always acquires the same simple geometrical shape (spherical dome) with the complication that, owing to end constraint, the dome does not possess uniform thickness. Now, using the established law of similarity, it can be assumed that if a uniform homogeneous sheet material were available in various gauges, then, provided strict testing conditions of similarity were observed, a wide range of die diameters could be employed, resulting in deformed domes which would also be exactly similar.

The important dimensions concerned would probably be restricted to:—

t = thickness of metal.
r = inner radius of die.
a = radius of die at " forming edge."

Then, provided that the ratios t/r and t/a were maintained constant throughout, a series of geometrically similar domes would be obtained, denoted by h/r = constant, where h denotes the height of the dome. It would also follow:—
(1) That the value of the Jovignot " cupping coefficient " (unit superficial exten-

TABLE II.

FLUID-PRESSURE (JOVIGNOT) TESTS IN GUILLERY MACHINE.

N.P.L. Identification Mark.	Material.	Thickness, in.	Height of dome at fracture (mm.)‡			Cupping coefficient.			Bursting pressure. lb. sq. in.		
			40 mm. die.	50 mm. die.	60 mm. die.	40 mm. die.	50 mm. die.	60 mm. die.	40 mm. die.	50 mm. die	60 mm. die.
FPW 1	Brass	0.018	11.4 [0.85]	16.9 [1.0]	25.6 [1.27]	0.32	0.45	0.73	1,930	1,610	1,430
FPW 2	Copper	0.016	12.3 [0.83]	18.6 [1.0]	22.7 [1.02]	0.38	0.55	0.57	1,205	1,025	840
FPW 4	Tinned iron	0.017	9.1 [0.77]	14.7 [1.0]	17.5 [0.99]	0.21	0.35	0.34	1,740	1,515	1,310
FPW 5	Tinned iron	0.026	—	12.0	—	—	0.23	—	—	2,280	—
FPW 6	Sheet iron	0.023	11.2 [0.90]	15.6 [1.0]	18.6 [1.0]	0.31	0.39	0.38	2,280	1,900	1,630
DDC 2	Aircraft Steel	0.013	—	>8.1†	—	—	>0.11†	—	—	>2,555†	—
DDC 3	Aircraft Steel	0.010	>7.2†	11.0	11.2	>0.13†	0.19	0.14	>2,555†	2,200	1,795
FWA 1, 2	Soft aluminium ...	0.079	—	14.3*	—	—	>0.33*	—	—	1,785*	—
FWA 4, 5	,, ,,	0.036	—	18.3	—	—	0.54	—	—	870	—
FWA 7, 8	,, ,,	0.019	—	17.8	—	—	0.51	—	—	430	—
FWA 10, 11	,, ,,	0.010	—	14.8	—	—	0.35	—	—	210	—
FWA 13, 14, 15	,, ,,	0.005	—	13.0	—	—	0.27	—	—	90	—
FVZ 27	70/30 brass, soft...	0.010	—	21.2	—	—	0.72	—	—	940	—
FVZ 29	H.C. Copper, soft	0.040	—	21.2	—	—	0.72	—	—	2,525	—
FVZ 30	H.C. Copper, soft	0.010	—	15.4	—	—	0.38	—	—	495	—

* Failed by shearing round edge of die.
† Reached limit of machine without fracturing.
‡ The figures in square brackets refer to the relative values of the ratio, height of dome to die radius, expressed in terms of the value for the 50 mm. die.

sion)* equal merely to $(h/r)^2$ would also be constant, (2) that the stress at fracture would be constant. But it is obviously impossible in practical testing—where a variety of sheet gauges and only a limited number of dies can be employed—to maintain the ideal conditions of similarity and a " scale effect " may be anticipated. This will be revealed most simply if it is found that, in tests made on the *same gauge* of material and using *different* dies, the ratio (h/r) is found to vary. To enable the relevant results of Table II to be examined in this respect, figures have been inserted—in square brackets—representing the relative values of the ratio

$$\frac{\text{Height of dome at fracture}}{\text{Inner radius of die}} = h/r.$$

It will be recognised that the materials used were not sufficiently homogeneous, nor are the results sufficiently numerous to enable definite conclusions to be drawn. Nevertheless, inspection does lead to the tentative conclusion that the 40 mm. die is too small. With the 50 mm. and 60 mm. dies (and, presumably, larger sizes), however, a nearly constant value of h/r has resulted, in three cases out of four, in spite of the absence of true similarity at the commencement of the test. This conclusion is of marked significance if the test is to be further employed, although much more experimental attention could be profitably devoted to the examination of this aspect. As the values of cupping coefficient given in Table II are merely proportional to the squares of the figures in brackets of the previous column, no detailed discussion of these values is necessary beyond recalling that these coefficients naturally give a more " open scale " than the values of the ratio of the height of dome to radius of die. This is really the point made by Jovignot when he attaches greater discriminating value to the fluid-pressure coefficient than to the " height of dome " value usually recorded in the more common type of cupping test.

The significance of the value of " bursting pressure " may be deferred until the later and more complete series of tests are discussed.

Fracture of the specimen generally occurred by splitting at or near the top of the dome. The shape and direction of the fracture is a useful indication of " directional " properties of the metal. It was usually found, as would be expected, that a metal which consistently split along the direction of rolling, exhibited in the tensile test, a relative weakness *across* the direction of rolling. Materials which proved to be equally strong in each direction, as judged by tensile tests, often exhibited curved lines of fracture or fractures inclined to the rolling direction, when burst in the fluid-pressure cupping test.

Complete records of height of cup and fluid pressure were taken in some of the tests. Typical plotted data are given in Fig. 4.

(*b*) *N.P.L. Machine for Fluid-Pressure Cupping Tests.*

The thickness of materials that can be tested in the Guillery machine is limited by the maximum permissible oil pressure, which is about 1 ton per sq. in. In order to use this form of test on the thicker metals available, an oil-pressure cupping machine having a capacity of 5 tons per sq. in. was designed and constructed. It was also considered that the usefulness of the machine would be increased by making provision for specimens up to 100 mm. dia.; also for means of obtaining an autographic record of the complete pressure-height diagram of each test.

* NOTE.—This corresponds to what is probably the most important factor in cold-pressing operations, and reveals the essential soundness of the principle of the test. Also, the fact that the dome is always *one* simple geometrical shape brings out one great inherent advantage of the test over the usual form of cupping test where dissimilar materials do *not* deform to the *same* shape.

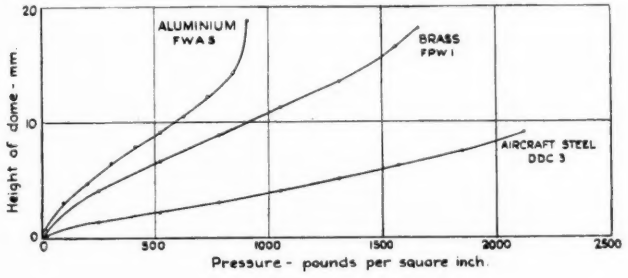

FIG. 4.

Typical pressure—height of dome curves obtained from fluid pressure tests made in Guillery machine (50 mm. die).

The testing machine and autographic recorder as constructed are shown in Fig. 5, with a 100 mm. dia. test piece in position. The test piece T is firmly

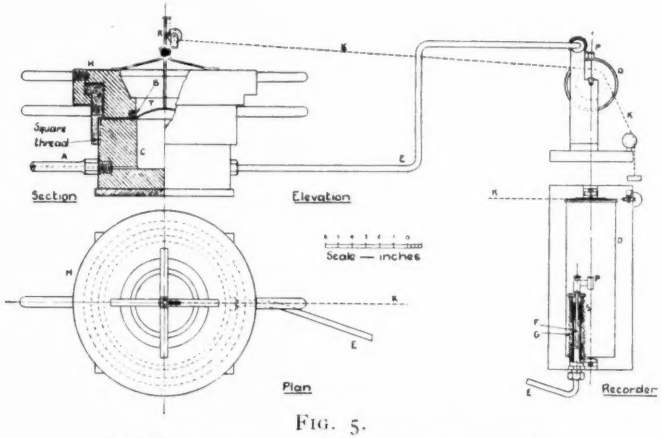

FIG. 5.

N.P.L. oil-pressure cupping testing machine.

clamped between the top face of the pressure chamber C and a hard steel die B, by screwing down the head H. As the latter has to be removed each time the specimen is replaced, it is made in two parts, connected by a bayonet fitting. Fig. 6 shows the method adopted of making an oil-tight joint between the lower

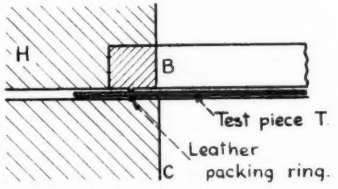

FIG. 6.

N.P.L. machine for oil-pressure cupping tests. Method of making oil-tight joint.

face of the specimen and the pressure chamber. A leather packing ring rests in an annular groove machined in the top face of the pressure chamber C. The specimen is pressed down upon this by a corresponding annular tongue projecting from the face of the clamping die B, which gives a high intensity of pressure on this ring when the head is screwed down tightly. The inner edge of the die is finished with a radius to prevent shearing of the test piece when the hydraulic pressure is applied. The pressure chamber C is filled with oil to which pressure is applied through the pipe A leading to an intensifier (not shown in the drawing) actuated by the platens of a 500-ton compression-testing machine. This pressure is transmitted to the recording apparatus through the pipe E. Increase of pressure moves the recording pen P along the axis of the drum D, on which a chart is fixed, while increase of the height of the " cup " causes the drum to revolve. Pressure is recorded in the following manner:—The recording pen is fixed to the end of a small plunger F. When pressure is transmitted to the cylinder G,

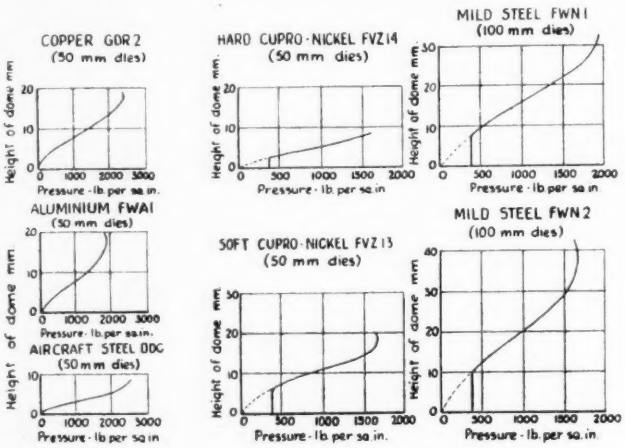

FIG. 7.

Typical autographic records obtained using the N.P.L. fluid-pressure cupping machine.

this plunger is pushed along the cylinder against the resistance of a calibrated spring S. By using a number of interchangeable springs of different stiffnesses, the scale of the diagram can be altered, according to the maximum pressure required. A cord K, passing round a pulley at one end of the drum D, serves to rotate the drum, and thus record the height of the " dome " in the specimen. A light rod R, guided vertically, rests on the centre of the test piece; to the top of this rod is fixed the end of the cord K, which rotates the drum.

For use with specimens of smaller diameter, a liner of the required internal diameter is fitted inside the pressure chamber; a corresponding die is fitted in the recess in the head. In this case, the oil pressure on the underside of the lower removable die assists in making the oil-tight joint with the test piece, and tests with 50 mm. dia. dies have been successfully carried out up to a bursting pressure of 6 tons per sq. in.

Typical autographic diagrams obtained in this machine are shown in Fig. 7. The numerical results obtained from the whole of the autographic diagrams are given in detail in Table III, each result representing the average of at least two separate tests.

TABLE III.

Fluid-Pressure Tests in N.P.L. Machine.

N.P.L. Identification Mark.	Material.	Thickness, in.	Height of dome at fracture (mm.).		Cupping coefficient.		Bursting pressure, lbs. per sq. in.	
			50 mm. die.	100 mm. die.	50 mm. die.	100 mm. die.	50 mm. die.	100 mm. die.
GDR 2	Copper	0.039	19.2 [1]	37.8 [0.99]	0.57	0.55	2,420	1,135
GDR 1	Copper	0.064	16.5 [1]	26.8 [0.81]	0.42	0.28	3,550	1,710
GDK	Planished steel	0.048	14.6 [1]	25.4 [0.87]	0.33	0.25	3,800	1,860
GDS	Planished steel	0.063	18.7 [1]	29.7 [0.79]	0.54	0.34	5,700	2,940
DDC 2	Aircraft steel	0.013	9.3	—	0.13	—	2,670	—
DDC 3	Aircraft steel	0.010	7.1	—	0.08	—	1,750	—
DVX	Aircraft steel	0.0225	10.0	—	0.16	—	4,270	—
DVY	Aircraft steel	0.0225	11.0	—	0.19	—	4,380	—
FVN 1	Mild steel	0.040	22.1	—	0.76	—	3,030	—
FVN 2	Mild steel	0.040	22.1	—	0.76	—	3,030	—
FWN 1	Mild steel	0.038	18.0 [1]	35.7 [0.99]	0.50	0.49	3,730	1,940
FWN 2	Mild steel	0.041	22.7 [1]	44.0 [0.97]	0.80	0.75	3,580	1,720
FVO 1	Cupro nickel-coated mild steel	0.032	18.3	—	0.52	—	2,660	—
FVO 4		0.032	22.1	—	0.76	—	3,120	—
FVO 5		0.033	20.9	—	0.68	—	2,970	—
FVO 6		0.034	21.6	—	0.72	—	3,170	—
FVO 7		0.034	22.1	—	0.76	—	3,200	—
HBI 1	Stainless steel as received	0.064	18.5	—	0.53	—	13,550	—
HBI 2	Stainless steel annealed	0.066	19.0	—	0.56	—	11,920	—
FVM 1	Zinc	0.100	14.0*	—	>0.30	—	3,620*	—
FVM 2	Zinc	0.060	20.7	—	0.66	—	2,040	—
FVM 3	Zinc	0.020	14.7	—	0.33	—	645	—
FVM 4	Zinc	0.010	17.0	—	0.45	—	295	—
FWA 1	Soft al.	0.079	20.0†	—	0.62	—	1,870	—
FVZ 25	70/30 brass, soft	0.060	24.9	—	0.96	—	5,500	—
FVZ 2	,, ,, hard	0.060	5.5*	—	>0.05	—	2,960*	—
FVZ 26	,, ,, soft	0.040	22.7	—	0.80	—	3,500	—
FVZ 4	,, ,, hard	0.040	5.8*	—	>0.05	—	2,730*	—
FVZ 5	,, ,, soft	0.020	21.3	—	0.70	—	1,880	—
FVZ 6	,, ,, hard	0.020	7.0	—	0.08	—	1,590	—
FVZ 8	,, ,, hard	0.010	5.2	—	0.04	—	625	—
FVZ 9	80/20 cupro nickel, soft	0.060	22.7	—	0.80	—	4,680	—
FVZ 10	,, ,, hard	0.060	11.8*	—	>0.22	—	5,530*	—
FVZ 11	,, ,, soft	0.040	21.3	—	0.70	—	3,220	—
FVZ 12	,, ,, hard	0.040	10.9	—	0.18	—	3,590	—
FVZ 13	,, ,, soft	0.020	19.7	—	0.60	—	1,680	—
FVZ 14	,, ,, hard	0.020	10.0	—	0.16	—	1,640	—
FVZ 15	,, ,, soft	0.010	18.9	—	0.55	—	785	—
FVZ 16	,, ,, hard	0.010	7.0	—	0.08	—	690	—
FVZ 28	H.C. copper, soft	0.060	22.0	—	0.75	—	3,690	—
FVZ 18	,, ,, hard	0.060	10.2*	—	>0.16	—	3,450*	—
FVZ 20	,, ,, hard	0.040	13.7†	—	0.29	—	2,690	—
FVZ 21	,, ,, soft	0.020	19.9	—	0.61	—	1,100	—
FVZ 22	,, ,, hard	0.020	11.0	—	0.19	—	1,300	—
FVZ 24	,, ,, hard	0.010	9.8	—	0.15	—	600	—

* Failed by shearing round edge of die.

† Some specimens also failed by shearing round edge of die.

Referring to Table III, six sheets have been tested using both 50 mm. and 100 mm. dies. To examine the degree of similarity of deformation, the relative values of the ratio height of dome to radius of die (h/r) have been inserted, in square brackets, in the appropriate column of the table. In three cases, the figures show that almost exact similarity of deformation has resulted; in the remaining three the agreement obtained is not good. But the interesting fact emerges that, in the larger die, the dome has not attained the size predicted from the result of the smaller specimen. Making suitable allowance for possible inhomogeneity of material and the probable errors involved in the readings, these general results suggest that, with *these* materials, the effect of the edge constraint of the die of 50 mm. dia. is such that scale effect at the larger size has become inappreciable. The fact that failure occurs somewhat prematurely in the larger die is a result to be expected, simply because a much greater surface of metal is under test with the accompanying greater probability of occurrence of local faults in the material. Although more extensive investigation is desirable, the above conclusion is of importance in the present stage of the more general examination of the test. It offers additional testimony to the inherent advantages of the fluid-pressure cupping method. It also suggests that a suitable die diameter for testing comparatively thick sheet need not be unduly large—probably of some dimension intermediate between 50 mm. and 100 mm.

Turning to the non-ferrous materials of Group (*c*), supplied in various gauges and two temper conditions, it is apparent that the relative values of the cupping coefficients bring out clearly the marked differences in ductility. Further discussion of these results can only usefully be made in comparison with the results obtained using other forms of cupping test; this comparison is made at the end of the paper.

Turning to the materials of Group (*b*), of which some information exists regarding their performance in cold pressing operations, the values of the Jovignot cupping coefficients may be examined in relation to the stated performances. Of the mild steels, FWN 1 and FWN 2, the former was stated to have proved unsatisfactory for deep pressing operations, while the latter was satisfactory. These relative behaviours are certainly accurately reflected in the cupping coefficients. The other samples of mild steel, FVN 1 and FVN 2, were both found unsatisfactory for deep pressings. Under the fluid-pressure test similar, but fairly high, cupping coefficient values were obtained, thus affording little useful information. As will be seen later, other forms of cupping test also gave values which were apparently satisfactory. The annealed stainless steel, HBI 2, was stated to be far superior to the corresponding sample, HBI 1, tested in the " as received " condition, but the cupping coefficients obtained differ only slightly; the Erichsen test also failed in a similar way. The tests on the cupro-nickel coated steel were very disappointing. No actual details as to the particular form of cold pressing concerned were made available, but it is understood that the failures encountered with these materials were :—7% (FVO 1 and 2), 14% (FVO 3 and 4), 23% (FVO 5), 95% (FVO 6), and 99% (FVO 7). But the cupping coefficients for these materials certainly gave no indications of these marked differences in performance, while the Erichsen, Guillery, A.E.G., and the K.W.I. tests also failed in this respect. It was certainly a matter of surprise to find that *all* types of cupping test failed in this manner, suggesting that the materials themselves *may* not have been the only factors responsible for these distinctly different performances in the press.

At a later stage, when the stress-deformation curves obtained in a fluid-pressure cupping test were studied in detail, it emerged that the discriminating possibilities of this test were probably very great, provided attention was not *confined* merely to the value of the cupping coefficient.

A very interesting aspect of the fluid-pressure cupping tests arises from a comparison of the estimated maximum stress induced in the fractured dome

(calculated using the formula for the strength of thin spherical shells, $f = PR/2t$) and the ultimate tensile stress of the material as obtained in the static tensile test. These figures, with their relative values, are given in Table IV. The figures relating to the bursting stress in the deformed sheet refer to the average values obtained using a die of 50 mm. dia. The value of the ratio p_e/p_t approximates to unity in a very large majority of cases in a very satisfactory manner in view of the known lack of uniformity of some of the materials. Possibly the use of a fluid-pressure test to destruction would not, normally, be worth while in replacement of a tensile test for cold pressing work, but the fact that the value of ultimate stress thus obtained refers to the sheet as a whole, rather than to any one particular direction, may offer advantages. Also, the test is very quickly carried out and requires no preparation of the test piece. For testing thick sheets, high fluid pressures are certainly required, but the devisement of a suitable apparatus might be worth while if routine tests are to be made. In connection with the testing of thin sheets for general purposes, the use of this test may well receive the consideration of those interested.*

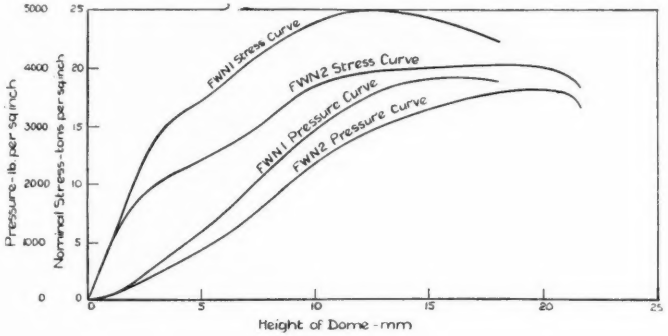

FIG. 8.

Curves of { *height of dome—pressure* / *height of dome—nominal stress* } *fluid pressure tests. Material FWN 1 and FWN 2.*

In the view of the authors, the complete stress-strain curve to fracture of a metal should furnish a very effective basis on which to assess the suitability of a material for cold pressing purposes. It was to examine this aspect that the N.P.L. fluid-pressure cupping machine was fitted with an autographic record to obtain complete height of dome-pressure curves (see Fig. 7). In Fig. 8 two curves of this type, relating to mild steel (FWN 1 and FWN 2), have been plotted to a large scale and exhibit marked differences between these materials. When these pressure readings are converted to *stress* in the material, curves are obtained—also see Fig. 8—which bring out these differences in even greater contrast. On general grounds, it would be expected that a material having a stress-deformation curve of the type associated with material FWN 2 would prove more satisfactory for cold pressing purposes than that associated with material FWN 1, and it may well be that the cause of the essential difference in behaviour of these materials in pressing has been most accurately revealed by these curves. This aspect can be studied further by re-plotting the data in the

* NOTE.—It may be recorded that this test has been found very useful at the N.P.L. for determining the tensile strength of very thin metal foils, the testing of which in the usual way presents considerable difficulties. These tests were carried out in the Guillery machine after fitting the same with a very sensitive manometer.

TABLE IV.

Comparison of Ultimate Tensile Stress and Maximum Stress in Fluid-Pressure Tests.

N.P.L. Identification Mark.	Material.	Thickness, in.	Ultimate tensile stress, tons per sq. in., *pt.*	Max. stress in cupping test. tons per sq. in. *pc.*	*pc*/*pt*
FPW 1	Brass	1.018	20.6	21.2	1.03
FPW 2	Copper	0.016	14.3	14.7	1.03
GDR 2	Copper	0.039	15.1	14.7	0.97
GDR 1	Copper	0.064	16.5	14.5	0.88
FPW 4	Tinned iron	0.017	22.9	22.4	0.98
FPW 5	Tinned iron	0.026	20.7	24.6	1.19
FPW 6	Sheet iron	0.023	18.9	20.2	1.07
GDK	Planished steel	0.048	24.8	22.2	0.90
GDS	Planished steel	0.063	24.4	22.7	0.93
DDC 2	Aircraft steel	0.013	75	83.3	1.11
DDC 3	Aircraft steel	0.010	74.5	78.8	1.06
DVX	Aircraft steel	0.0225	86	65.0	0.76
DVY	Aircraft steel	0.0225	89	62.5	0.70
FVN 1	Mild steel	0.040	21.5	21.8	1.01
FVN 2	Mild steel	0.040	21.4	22.0	1.03
FWN 1	Mild steel	0.038	25.9	25.0	0.97
FWN 2	Mild steel	0.041	21.3	20.4	0.96
FVO 1, 2	Cupro-nickel coated mild steel	0.032	20.8	21.8	1.05
FVO 3, 4		0.032	21.4	23.0	1.07
FVO 5		0.033	22.0	21.7	0.99
FVO 6		0.034	23.9	22.7	0.95
FVO 7		0.034	23.3	23.6	1.01
HBI 1	Stainless steel as received	0.064	57.9	50.0	0.86
HBI 2	Stainless steel, annealed	0.066	49.3	42.0	0.85
FVM 1	Zinc	0.100	10.5	9.9	0.94
FVM 2	Zinc	0.060	8.3	8.3	1.00
FVM 3	Zinc	0.020	9.2	8.6	0.94
FVM 4	Zinc	0.010	8.0	7.9	0.99
FWA 1, 2, 3	Soft aluminium	0.079	6.2	5.8	0.94
FWA 4, 5, 6	Soft aluminium	0.036	5.9	5.6	0.95
FWA 7, 8, 9	Soft aluminium	0.019	5.8	5.3	0.91
FWA 10, 11, 12	Soft aluminium	0.010	6.0	5.2	0.87
FWA 13, 14, 15	Soft aluminium	0.005	5.5	4.8	0.87
FVZ 1, 25	70/30 Brass, soft	0.060	21.8	20.7	0.95
FVZ 2	,, ,, hard	0.060	42.8	>27.2	—
FVZ 3,26	,, ,, soft	0.040	21.5	20.3	0.95
FVZ 4	,, ,, hard	0.040	41.8	>36.2	—
FVZ 5	,, ,, soft	0.020	22.5	21.7	0.96
FVZ 6	,, ,, hard	0.020	38.3	30.9	0.96
FVZ 7, 27	,, ,, soft	0.010	21.4	20.9	0.08
FVZ 8	,, ,, hard	0.010	38.1	36.8	0.96
FVZ 9	80/20 Cup. Ni, soft	0.060	21.0	18.3	0.87
FVZ 10	,, ,, hard	0.060	34.5	>28.1	—
FVZ 11	,, ,, soft	0.040	21.9	18.8	0.86
FVZ 12	,, ,, hard	0.040	36.3	28.8	0.79
FVZ 13	,, ,, soft	0.020	22.2	20.4	0.92
FVZ 14	,, ,, hard	0.020	32.4	29.9	0.92
FVZ 15	,, ,, soft	0.010	22.5	19.1	0.85
FVZ 16	,, ,, hard	0.010	33.7	27.3	0.81
FVZ 17, 28	H.C. Copper, soft	0.060	15.8	14.6	0.92
FVZ 18	,, ,, hard	0.060	24.6	>18.9	—
FVZ 19, 29	,, ,, soft	0.040	15.9	14.1	0.89
FVZ 20	,, ,, hard	0.040	25.4	23.1	0.91
FVZ 21	,, ,, soft	0.020	14.5	13.0	0.90
FVZ 22	,, ,, hard	0.020	26.6	20.6	0.78
FVZ 23, 30	,, ,, soft	0.010	15.4	12.2	0.79
FVZ 24	,, ,, hard	0.010	24.3	24.1	0.99

Note.—Stresses calculated from results of tests in Guillery machine are obtained from the maximum height and pressure, and may be slightly less than the true maximum stress.

form of stress-superficial strain curves; this has been done in Fig. 9, where the essential difference in mode of plastic deformation is even more strongly brought out. It was of interest to compare these curves with the tensile load-elongation curves to fracture for the same materials; the latter were determined and are included in Fig. 9. A very marked similarity is seen to exist between the two types of curves. The forms of the curves—taken in conjunction with the known superiority of material FWN 2 in cold pressing—support the practical experience of manufacturers of automobile steel pressings that a low yield point and good general elongation are important factors on which to assess the value of a material for cold pressing purposes. As stress-cupping coefficient curves possess the additional advantage that they relate to *superficial* strain, it may prove that they are more valuable than tensile curves; the former may, in fact, prove to be a completely satisfactory method of assessment.

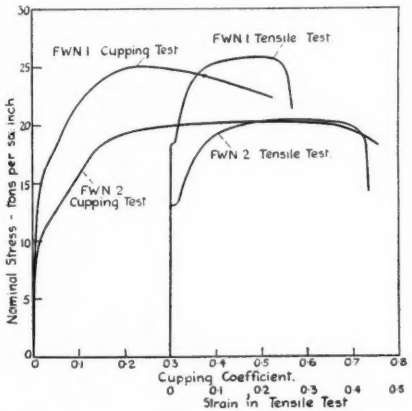

FIG. 9.

Stress-strain curves. Material FWN 1 and FWN 2.

Figs. 8 and 9 relate to materials whose relative cold pressing values were found to be reflected in the values of the " cupping coefficient." It was decided to repeat the analysis with two steels to which this correspondence did not apply. Similar curves, reproduced as Figs. 10 and 11, have therefore been prepared for the stainless steels HBI 1 and HBI 2. The curves of Fig. 11 do indeed disclose marked differences between the two materials which appear to reflect the practical experience that material HBI 2 is preferable to HBI 1 for drawing purposes.*

The values of " stress " plotted in Figs. 8-11 are only nominal, being estimated merely using the *original* thickness of the material. Actual stress-strain curves can, of course, be obtained in a tensile test by taking observations of the changes in cross section of the specimen as the test proceeds; such tests are occasionally made on round bars, but are somewhat difficult to carry out on test pieces cut from sheets; in fact, as far as the authors are aware, no such curves for sheet metal have previously been published. Fairly satisfactory tests of this type were made on the samples of stainless steel, with the results recorded in Fig. 12. These curves reveal the very high stresses at fracture which actually are in operation, but the general shapes of the curves are very similar to those of

* Since the preparation of this paper, curves, similar to Figs. 8 and 9, have been prepared for the Cupro-nickel-coated Mild Steel (FVO). Although differences are thereby revealed between the various samples, these differences do *not*, in themselves, appear sufficient to account for the very different behaviour, in practical drawing, of these materials.

Fig. 11, which are much easier to obtain. It does not appear that the more accurate information given in Fig. 12 is of greater service, from a cold pressing point of view, than that of Fig. 11.

The general conclusion drawn from this study of the complete deformation curves is that, probably, very valuable information, with regard to the suitability of a metal for cold pressing operations, can be obtained from a complete load-extension diagram; such diagrams are much more discriminating than the usual

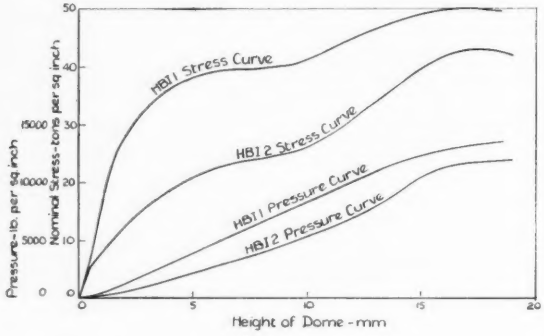
HB1 Stress Curve
HB1 2 Stress Curve
HB1 Pressure Curve
HB1 2 Pressure Curve
Pressure-lb. per sq. inch
Nominal Stress-tons per sq. inch
Height of Dome - mm

FIG. 10.

Curves of { *height of dome—pressure* / *height of dome—nominal stress* } *fluid pressure tests. Materials HBI 1 and HBI 2.*

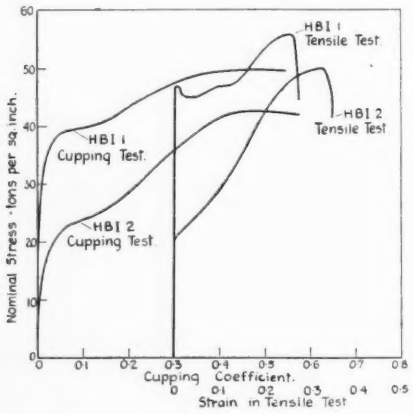
HBI 1 Tensile Test
HBI 2 Tensile Test
HBI 1 Cupping Test
HBI 2 Cupping Test
Nominal Stress - tons per sq. inch.
Cupping Coefficient.
Strain in Tensile Test

FIG. 11.

Stress-strain curves. Materials HBI 1 and HBI 2.

tensile test data (yield, ultimate, elongation) or the bursting stress and " cupping coefficient " obtained from a cursory fluid-pressure cupping test. Although complete tensile deformation curves (taken in two directions at right angles) may supply the necessary information, it is fair to assume that a stress-deformation curve obtained in a cupping test is even more useful and may be easier to obtain.

Thus, it is concluded that the fluid-pressure cupping test may prove of great value in the cold pressing Industry; the further exploration of this test certainly appears desirable.

Apart from cold pressing, the fluid-pressure cupping test may possess interest in connection with the testing of thin sheet metal in general. In such testing, cupping tests using a distending tool find a wide application, but the work of Cook and Larke* led them to conclude that " Cupping tests, although they may measure some kind of ductility and, if properly correlated, may afford a good sound indication of the behaviour of a material for cupping and drawing operations, are limited in respect to specification work because of the variability of results given by different machines." To afford some information on this important point with regard to the fluid-pressure cupping test, the results given in

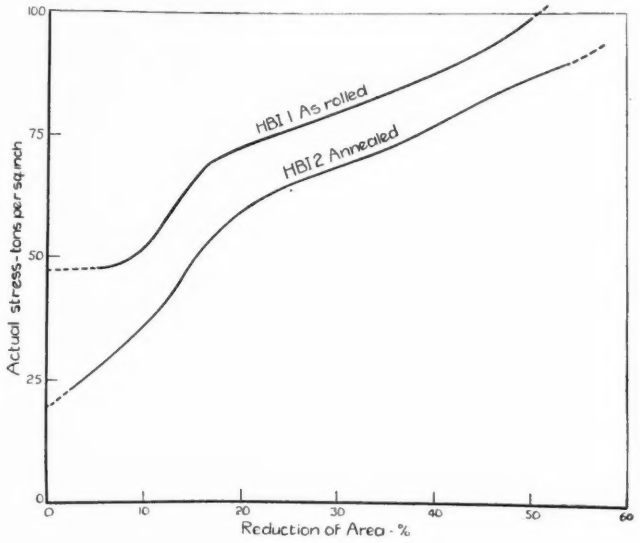

FIG. 12.

Complete tensile stress-deformation curves for stainless steel.

Table V are presented. They refer to tests made using the Guillery machine (fitted with the Jovignot attachments) and the N.P.L. machine. The materials used are exactly the same as those used by Cook and Larke in their work. As would be expected, greater variations are encountered with hard than with softer materials; the former are likely to be more sensitive to experimental variations in test conditions. A series of results (not included in Table V) from identical materials tested in the two available machines showed fair agreement. With the fluid-pressure type of cupping test the only obvious factor likely to cause variation in the results obtained is the degree of clamping of the test specimens. Inspection of specimens after test indicated that, in nearly all cases, stretching of the metal occurred in the neighbourhood of the edges of the dies and also between the dies; no doubt this could be reduced by improved clamp design.

* *Loc. cit.*

TABLE V.

VARIATION OF RESULTS.

FLUID-PRESSURE CUPPING TESTS (50 MM. DIES).

N.P.L. Identification Mark.	Material.	Thickness, in.	No. of tests.	Max. pressure, lb. per sq. in.		Max. height (mm.).	
				Average.	Max. variation, per cent.	Average.	Max. variation, per cent.
FVZ 25	70/30 Brass, soft	0.060	2 (N)	5,500	± 1.2	24.9	± 2.0
FVZ 26	,, ,, soft	0.040	2 (N)	3,500	± 0.3	22.7	± 2.8
FVZ 5	,, ,, soft	0.020	2 (N)	1,880	± 3.6	21.3	± 0.6
FVZ 6	,, ,, hard	0.020	2 (N)	1,590	± 2.8	7.0	± 10.0
FVZ 27	,, ,, soft	0.010	2 (G)	940	± 0.5	21.2	± 2.4
FVZ 8	,, ,, hard	0.010	2 (N)	625	± 0.4	5.2	± 12.2
FVZ 9	80/20 Cu Ni, soft	0.060	2 (N)	4,680	± 0.5	22.7	± 0.3
FVZ 11	,, ,, soft	0.040	2 (N)	3,220	± 0.3	21.3	± 1.5
FVZ 12	,, ,, hard	0.040	2 (N)	3,590	± 3.4	10.0	± 14
FVZ 13	,, ,, soft	0.020	2 (N)	1,680	± 1.3	19.7	± 1.9
FVZ 14	,, ,, hard	0.020	2 (N)	1,640	± 2.4	10.0	± 11.4
FVZ 15	,, ,, soft	0.010	2 (N)	785	± 2.9	18.9	± 4.7
FVZ 16	,, ,, hard	0.010	2 (N)	690	± 11.4	7.0	± 27
FVZ 28	H.C. Copper, soft	0.060	2 (N)	3,690	± 0.6	22.0	± 1.7
FVZ 29	,, ,, soft	0.040	2 (G)	2,525	± 1.0	21.2 (1 result only)	—
FVZ 21	,, ,, soft	0.020	2 (N)	1,100	± 4.1	19.9	± 0.3
FVZ 22	,, ,, hard	0.020	2 (N)	1,300	± 3.5	11.0	± 9.8
FVZ 30	,, ,, soft	0.010	2 (G)	495	—	15.4	± 3.4
FVZ 24	,, ,, hard	0.010	2 (N)	600	± 2.4	9.8	± 8.4
FPW 1	Soft brass	0.018	7 (G)	1,610	+4.7 / −5.6	16.9	+15.5 / −8.4

(N) Tests carried out in N.P.L. Machine. (G) Tests carried out in Guillery Machine.

III. COMPARISON OF THE VARIOUS MEASURES OF DUCTILITY AFFORDED BY SEVERAL FORMS OF CUPPING TEST

In order to compare the oil pressure test with other forms of cupping test, a number of the materials available were also subjected to Erichsen, Avery, Guillery, and K.W.I. cupping tests, also to a test using a cylindrical tool of the same type as the A.E.G. test. As the latter test is not identical with the original A.E.G. test, it is for convenience referred to in the present paper as the " A.E.G. type " test. A short description of each of the foregoing tests is given below, followed by a detailed comparison of the results recorded in Table VI.

(*a*) *The Erichsen Test.*

The Erichsen, Avery and Guillery cupping tests are all of the general type illustrated diagrammatically in Fig. 1, differing from one another only in details. The standard Erichsen test uses a tool with a spherical end of 20 mm. dia. to deform the test piece, which is held between annular jaws of 27 mm. internal dia. The test sheet, which is $3\frac{1}{2}$in. sq., is first clamped between the jaws to measure the thickness; the jaws are then moved apart by 0.05 mm. and clamped in that position, to allow the metal to be drawn into the cup as the test progresses. The tool is pressed into the metal until a crack appears in the cup, and the depth of cup at this instant is taken as a measure of the ductility of the metal. In the present tests the end of the tool and the edge of the dies were greased. A few

preliminary experiments made on brass sheet (FPW 1) at widely different speeds of testing showed the effect of speed to be negligible, but this is probably not generally true of all metals.

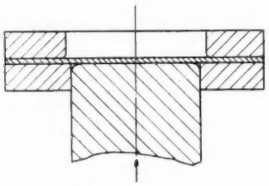

FIG. 13A.
A.E.G. type test.

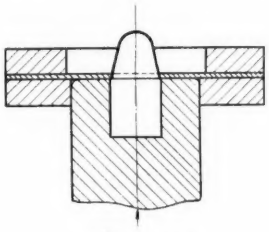

FIG. 13B.
K.W.I. test.

(*b*) *The Avery Test.*

The dimensions of tool and dies in this testing machine are identical with those of the Erichsen machine, but the Avery machine has the advantage of being

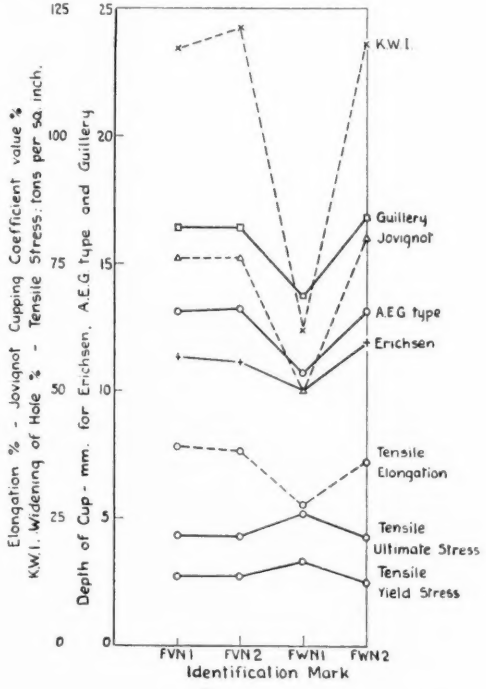

FIG. 14.
Comparison of cupping tests on mild steel.

portable; it can be used in an ordinary vice. The chief difference between the Erichsen and Avery tests is that the latter is provided with reversible dies, one side being plain and the other serrated. The test piece is a strip 2in. wide and is tested first between the smooth dies with 0.05 mm. play as in the Erichsen

test; it is then moved along and tested while clamped tightly between the serrated jaws. It is suggested by the makers that the difference between the values given by these two tests is an indication of the " workability " of the metal, as distinct from the " ductility," giving a value which is important in relation to pressing operations.

(*c*) *The Guillery Test.*

The spherical distending tool of the Guillery test has a diameter of 20 mm., as employed in the Erichsen test, but the diameter of the dies is 50 mm. Load is applied to the tool by hydraulic pressure, a gauge being provided to measure

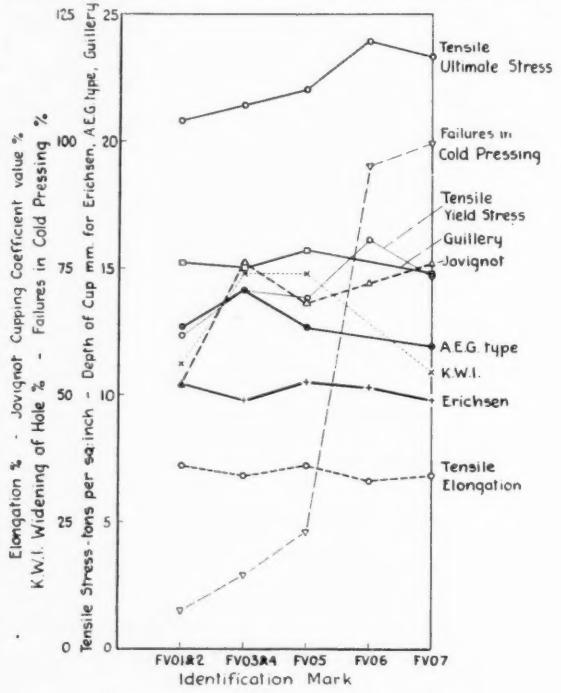

FIG. 15.

Comparison of cupping tests on cupro-nickel coated mild steel.

the maximum force on the tool; the test is continued until the pressure reaches a maximum and begins to fall. This end-point is usually more clearly defined than the end-point in the Erichsen test. The size of test piece, which is clamped tightly, is generally 90 mm. square; both maximum force and depth of cup are recorded.

(*d*) *The A.E.G. Type Test.*

This test is similar to the Guillery test, except for the shape of the distending tool employed, which, instead of being spherical at the end, is cylindrical with a rounded edge, as shown in Fig. 13a. The tool used in the present tests was 40 mm. dia. with an edge radius of 5 mm., and the tests were carried out in the Guillery machine. Fracture of the specimen occurs round the edge of the cylinder. The diameter of dies was 50 mm., as in the Guillery test.

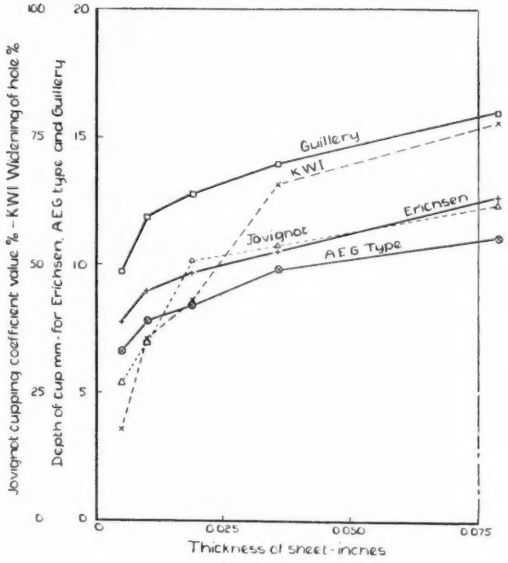
Jovignot cupping coefficient value % - KWI Widening of hole %
Depth of cup mm - for Erichsen, AEG type and Guillery
Guillery
KWI
Erichsen
Jovignot
AEG Type
Thickness of sheet - inches

FIG. 16.

Comparison of cupping tests on soft aluminium.

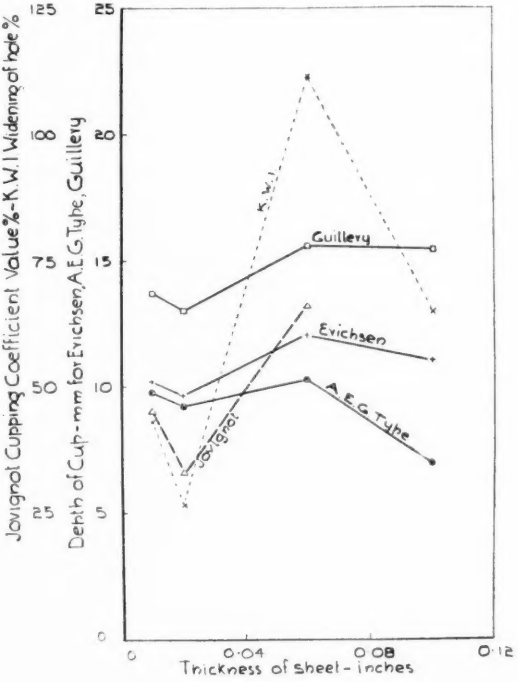
Jovignot Cupping Coefficient Value % - K.W.I. Widening of hole %
Depth of Cup - mm for Erichsen, A.E.G. Type, Guillery
K.W.I.
Guillery
Erichsen
A.E.G. Type
Jovignot
Thickness of sheet - inches

FIG. 17.

Comparison of cupping tests on zinc.

TABLE VI.

Comparison of Cupping Tests.

N.P.L. Identification Mark.	Material.	Thickness, in.	Tensile test. Elongation on 2in., per cent.	Fluid pressure test, 50 mm. dies.		Erichsen test. Depth of cup, mm.	Avery test. Depth of cup, mm.		Guillery test. Depth of cup, mm.	A.E.G. type of test. Depth of cup, mm.	K.W.I. test.	
				Height of dome.	Cupping coefficient.		Slip.	Clipped.			Depth of cup, mm.	Widening hole, per cent.
FPW 1	Brass	0.018	>21	16.9	0.45	10.2	10.7	9.3	12.7	16.0	8.4	65.5
FPW 2	Copper	0.016	>21	18.6	0.55	11.7	11.55	9.55	14.85	13.8	7.2	41
GDR 2	Copper	0.039	38	19.2	0.57						11.8	61
GDR 1	Copper	0.064	37	16.5	0.42	9.4			11.4	7.9	9.65	50
FPW 4	Tinned iron	0.017	17	14.7	0.35	7.4	7.75	6.85	9.5	10.7	5.8	27
FWP 5	Tinned iron	0.026	13	12.0	0.23	7.9			10.6	10.8	5.65	26.5
FPW 6	Sheet iron	0.023	21	15.6	0.39	9.0	9.05	8.95	12.4		7.0	42.5
DGK	Planished steel	0.048	11	14.6	0.33	9.3			11.7	7.3	7.3	29
GDS	Planished steel	0.063	24	18.7	0.54	10.2			13.9	>7.6	10.2	53.5
DDC 2	Aircraft steel	0.013	—	9.3	0.13	5.7			7.15	5.6	3.75	9
DDC 3	Aircraft steel	0.010	—	11.0	0.19	5.5	5.9	5.9	7.7	5.5	3.3	7
				7.1	0.08							
DVX	Aircraft steel	0.0225	5	10.0	0.16							
DVY	Aircraft steel	0.0225	5.5	11.0	0.19							
FVN 1	Mild steel	0.040	39	22.1	0.76	11.3			16.4	13.1	14.8	117
FVN 2	Mild steel	0.040	38	22.1	0.76	11.1			16.4	13.2	15.0	121
FWN 1	Mild steel	0.038	27.5	18.0	0.50	10.0			13.7	10.7	11.0	62
FWN 2	Mild steel	0.041	35.5	22.7	0.80	11.9			16.8	13.1	15.2	118
FVO 1 & 2	Cupro-nickel coated mild steel	0.032	36	18.3	0.52	10.4			15.2	12.65	10.8	56
FVO 3 & 4		0.032	34	22.1	0.76	9.8			15.0	14.1	12.3	74
FVO 5		0.033	36	20.9	0.68	10.5			15.7	12.65	11.9	74
FVO 6		0.034	33	21.6	0.72	10.3						
FVO 7		0.034	34	22.1	0.76	9.8			14.8	11.9	10.4	54
HBI 1	Stainless steel as received	0.064	28.5	18.5	0.53	11.8						
HBI 2	Stainless steel annealed	0.066	35	19.0	0.56	12.8						

FVM 1	Zinc	0.100	44	>14.0	>0.30	11.1			15.45	7.0	12.4	65
FVM 2	Zinc	0.060	59	20.7	0.66	12.05			15.6	10.3	14.8	111
FVM 3	Zinc	0.020	>19	14.7	0.33	9.65			13.0	9.2	7.4	26.5
FVM 4	Zinc	0.010	>17	17.0	0.45	10.2			13.7	9.75	9.0	43
FWA 1, 2, 3	Soft aluminium	0.079	36	20.0	0.62	12.7			16.0	11.1	12.3	78
FWA 4, 5, 6	Soft aluminium	0.036	>14	18.3	0.54	10.55			14.0	9.85	10.9	66
FWA 7, 8, 9	Soft aluminium	0.019	>12.5	17.8	0.51	9.7			12.8	8.4	8.7	43
FWA 10, 11, 12	Soft aluminium	0.010	>11.5	14.8	0.35	9.0			11.9	7.8	7.5	35.5
FWA 13, 14, 15	Soft aluminium	0.005	>11	13.0	0.27	7.8			9.75	6.6	5.15	18
FVZ 1 & 25	70/30 brass, soft	0.060	70	24.9	0.96	14.7	15.1		21.0	>12.8	16.7	115
FVZ 2	70/30 brass, hard	0.060	7	>5.5	>0.05	4.0	2.5					
FVZ 3 & 26	70/30 brass, soft	0.040	66.5	22.7	0.80	14.1	14.25		20.9	19.1	14.9	99
FVZ 4	70/30 brass, hard	0.040	2	>5.8	>0.05	3.8	3.8					
FVZ 5	70/30 brass, soft	0.020	63	21.3	0.70	12.6	12.5					
FVZ 6	70/30 brass, hard	0.020	0	7.0	0.08	5.0	4.1					
FVZ 7 & 27	70/30 brass, soft	0.010	52	21.2	0.72	11.7	10.6		17.3	16.0	11.4	54
FVZ 8	70/30 brass, hard	0.010	0	5.2	0.4	4.0	3.5					
FVZ 9	80/20 Cu-Ni, soft	0.060	43	22.7	0.80	12.7	12.5					
FVZ 10	80/20 Cu-Ni, hard	0.060	4.5	>11.8	>0.22	8.5	8.1					
FVZ 11	80/20 Cu-Ni, soft	0.040	41	21.3	0.70	12.0	12.1					
FVZ 12	80/20 Cu-Ni, hard	0.040	4	10.9	0.18	7.5	7.2					
FVZ 13	80/20 Cu-Ni, soft	0.020	36	19.7	0.60	10.75	10.8					
FVZ 14	80/20 Cu-Ni, hard	0.020	2	10.0	0.16	6.8	5.9					
FVZ 15	80/20 Cu-Ni, soft	0.010	31	18.9	0.55	10.1	9.4					
FVZ 16	80/20 Cu-Ni, hard	0.010	0	7.0	0.08	5.2	4.7					
FVZ 17 & 28	H.C. copper, soft	0.060	47	22.0	0.75	12.5	12.5		17.8	12.8	13.3	94
FVZ 18	H.C. copper, hard	0.060	3	<10.2	>0.16	7.6	7.0					
FVZ 19 & 29	H.C. copper, soft	0.040	44.5	21.2	0.72	11.8	12.2		16.9	13.2	12.9	78
FVZ 20	H.C. copper, hard	0.040	3.5	13.7	0.29	6.6	6.1					
FVZ 21	H.C. copper, soft	0.020	35.5	19.9	0.61	10.9	10.4					
FVZ 22	H.C. copper, hard	0.020	2	11.0	0.19	6.5	5.2					
FVZ 23 & 30	H.C. copper, soft	0.010	8	15.4	0.38	10.3	9.5		15.5	10.2	8.2	34
FVZ 24	H.C. copper, hard	0.010	0	9.8	0.15	5.1	4.6					

Erichsen and Avery results on FVZ materials by Cook and Larke. Erichsen tests on FVO materials from Woolwich Research Department.

(*e*) *The K.W.I. Test.*

This test, which has been developed by Siebel and Pomp at the Kaiser Wilhelm Institut für Eisenforschung at Dusseldorf, differs in principle from all the foregoing cupping tests. Fig. 13b shows the type of tool used. A cylindrical tool in size the same as that used for the A.E.G. test, has a projection 12 mm. dia. on the face of the tool. The test piece, 90 mm. square, has a central hole, reamered out to 12 mm. dia., with all burrs carefully removed from the edge. The test may be carried out in the Guillery machine, the projection in the centre of the tool face serving to centre the hole at the beginning of the test, which is continued until a crack appears at the edge of the hole. The diameter of the hole is then measured and the ductility is expressed as the percentage widening of the hole.

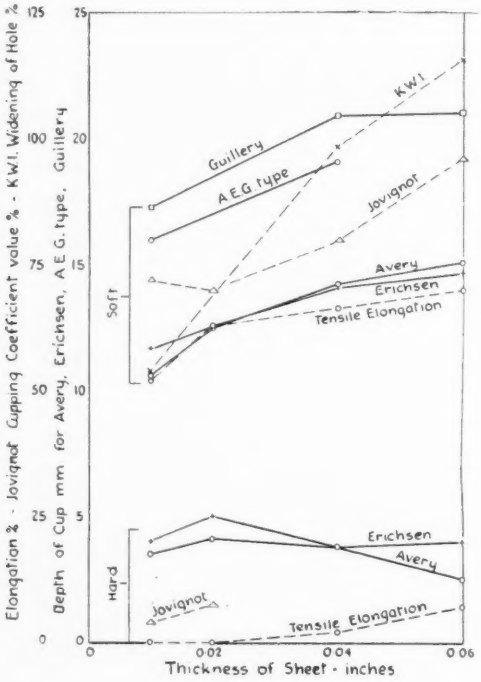

FIG. 18.

Comparison of cupping tests on 70/30 brass.

(*f*) *Comparison of Various Cupping Tests, Discussion of Results.*

To afford convenient comparison of results, the " ductility " values obtained in the various cupping tests have been plotted, for various materials, in Figs. 14, 15, 16, 17, 18, 19, and 20; in some cases, data obtained in tensile tests are also included. Considering first the test results on mild steel shown in Fig. 14, it will be noted that all the ductility tests (including elongation in the tensile test) show material FWN 1 to be inferior to the three other materials, this difference being brought out most clearly by the Jovignot, also the K.W.I. tests. With regard to the remaining three materials, little differences only are indicated by the cupping tests; it is apparent that all five types of test are reflecting the same

property of the materials. As materials FVN 1 and FVN 2 were both stated to have given poor performance in pressing, it is clear that no indication of this fact is afforded by any measures of ductility used in the tests.

Fig. 15 compares the results of the various tests made on the cupro-nickel coated mild steel. None of the cupping tests offers any indication of the wide differences of behaviour of these materials in service pressing operations. The

TABLE VII.

Consistency of Results.

Guillery Tests.

N.P.L. Identification Mark.	Material.	Thickness, in.	No. of Tests.	Height of cup at fracture (mm.).	
				Average.	Max. variation, per cent.
FVZ 25	Soft 70/30 Brass	0.060	2	21.0	±0.2
FVZ 26	,, ,, ,, ...	0.040	2	20.9	±0.2
FVZ 27	,, ,, ,, ...	0.010	2	17.3	±2.9
FVZ 28	Soft H.C. Copper	0.060	2	17.8	±1.7
FVZ 29	,, ,, ,, ...	0.040	2	16.9	±0.9
FVZ 30	,, ,, ,, ...	0.010	2	15.5	±1.6
				Average .	±1.3

A.E.G. Type Tests.

N.P.L. Identification Mark.	Material.	Thickness, in.	No. of Tests.	Height of cup at fracture (mm.).	
				Average.	Max. variation, per cent.
FVZ 26	Soft 70/30 Brass	0.040	2	19.1	±1.6
FVZ 27	,, ,, ,, ...	0.010	2	16.0	0
FVZ 28	Soft H.C. Copper	0.060	2	12.8	±2.0
FVZ 29	,, ,, ,, ...	0.040	2	13.2	0
FVZ 30	,, ,, ,, ...	0.010	2	10.2	±1.0
				Average .	±0.9

K.W.I. Tests.

N.P.L. Identification Mark.	Material.	Thickness, in.	No. of Tests.	Percentage widening of hole.	
				Average.	Max. variation, per cent.
FVZ 25	Soft 70/30 Brass	0.060	2	115	±3.3
FVZ 26	,, ,, ,, ...	0.040	2	99	±2.0
FVZ 27	,, ,, ,, ...	0.010	2	54	±0.9
FVZ 28	Soft H.C. Copper	0.060	2	94	±1.9
FVZ 29	,, ,, ,, ...	0.040	2	78	±0.1
FVZ 30	,, ,, ,, ...	0.010	2	34	±0.8
				Average .	±1.5

values of ultimate tensile stress alone bear any relation to the suitability in service, but the actual differences are very small. The curves for tensile elongation, Erichsen and Guillery tests in Fig. 15, are of similar form, but those relating to the Jovignot, A.E.G. type, and K.W.I. tests are quite irregular.

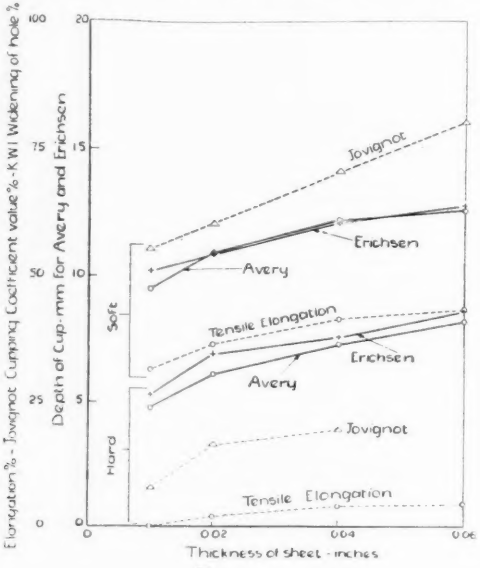

FIG. 19.

Comparison of cupping tests on 80/20 cupro-nickel.

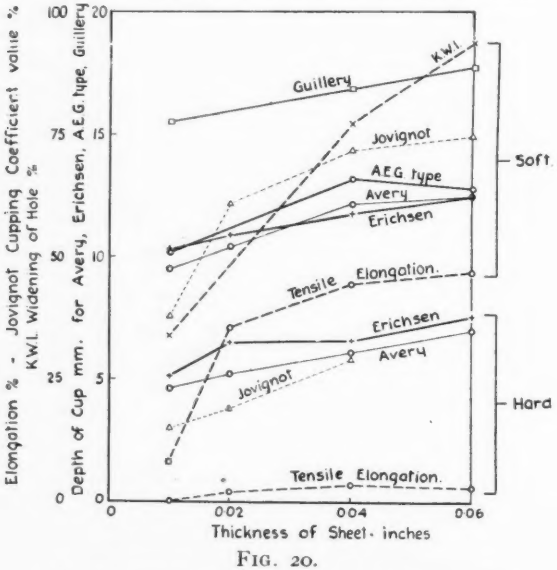

FIG. 20.

Comparison of cupping tests on H.C. copper.

Figs. 16, 17, 18, 19, and 20, in which the various values obtained on materials of different thickness are shown, cannot be discussed in relation to the service behaviour of the materials of which no information is available. The chief point of interest is that the curves for the different tests are of roughly the same general form for each set of materials; the open scale given by the K.W.I. test and, to a lesser extent, by the oil pressure test, *may* be a point in favour of these tests. But, in general, the results of the present comparative series of tests do not suggest that, as a measure of ductility, any one form of cupping test possesses marked advantages over the others, or over the elongation value obtained in the tensile test, when the results are confined to the type of data plotted in Figs. 14 to 20.

Table VII has been prepared to indicate the satisfactory measure of consistency of results obtained in the present investigation using the Guillery, A.E.G., and K.W.I. tests.

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The bibliography, given in the Appendix, which may be useful to others interested, is not intended as a complete list of references. It contains merely a number of publications relating to cupping tests and the testing of sheet metal which the authors found of great interest in the early stages of the present research, together with a few more recent references of special interest.

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COLD PRESSING AND DRAWING—THE METALLURGICAL ASPECT *

BY

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The process of cold pressing can only be applied to the more ductile metals, and the greater part of the material so treated is in the form of thin sheets. Leaving out of account such exceptional materials as lead, a ductile metal is appreciably hardened in the process, losing some of its ductility and having its " elastic limit " raised. It can be restored more or less completely by annealing, according to the temperature and the time of treatment. In addition, changes in ductility may occur in course of time, even at atmospheric temperatures.

The metals used for the purpose include steel, mostly of the low carbon variety, copper, brass, cupro-nickel, nickel-silver, aluminium, and the alloy steels of the ductile " stainless " type. Each of these metals presents its own special characteristics, but certain properties must be common to all. These include: sufficient ductility, absence of marked directional properties, and uniform (usually small) grain size, whilst uniformity of texture throughout the thickness, although not always attainable, is recognised as desirable.

Low-carbon steel being the material used in the largest quantities, and presenting certain problems peculiar to itself, has received the greatest amount of attention. Soft iron and such steels as consist mainly of ferrite, are anomalous in giving a marked " yield " when deformed, the strain increasing without increase of stress. Other metals behave elastically over a limited range of stress, and then deform, more rapidly, the so-called yield point being the stress at which an arbitrarily determined deformation has been reached, but with the ferritic steels in the soft condition, actual flow occurs, shown in the mechanical testing of thin sheet steel by the spreading of characteristic figures over the surface, the process occupying a measurable time, and on the autographic load-strain diagram by a drop followed by a horizontal portion of the curve. Rather curiously, this behaviour does not appear to be characteristic of iron of the highest purity. In cold-worked material the effect becomes less marked, and with a sufficient degree of cold-working it disappears entirely.

Since the deformation of a metal occurs by means of slip along crystal planes, the actual change of shape of a crystal will depend on its orientation relatively to the direction of stress. With very small crystals composing a sheet, these differences of orientation will be averaged, and the material will behave as if sensibly isotropic, but with large crystals an irregular surface will be apparent when the metal is deformed by pressing in a die. The " orange peel," and similar roughenings of surface, are mainly due to this cause, which affects all metals, and not only steel. For this reason, a small grain size is to be preferred, but the smaller the grain, other things being equal, the harder and less ductile a material, so that in practice a compromise has to be accepted, and certain standard sizes of crystal grain are aimed at in the production of sheets suitable for cold pressing or deep drawing. In thin sheets of very low carbon steel, especially with high phosphorus, the special type of brittleness described

* A paper read at a joint meeting of the Institution of Automobile Engineers, the Royal Aeronautical Society, and other Technical Institutions and Societies.

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by Stead (1) may appear if the grains are very large, but this peculiar defect can usually be avoided at the present day.

When fine-grained soft steel is pressed, however, it is very liable to develop " stretcher strains," or bands of unequally work-hardened metal, producing a pattern which disfigures the surface. These appear immediately the yield point is reached, and are a consequence of the anomalous behaviour of ferritic materials at that point. In general, the direction of these bands follows that of the " Lüders lines," which are seen when the scale is detached from a deformed piece of black steel, these directions being independent of crystal structure and appearing on non-metallic materials as well as on metals, but stretcher strains are usually less straight, tending towards flambent forms, and the severely strained bands are harder than the neighbouring regions of less strain by about 5 per cent. (2), (3), (4). They are prevented by cold-rolling, but as this hardens the steel and makes it less ductile, the remedy is not usually applicable. The difficulty is got over by passing the sheet through a levelling machine, in which it is lightly cold-worked by passing between staggered rollers, a slight stretch being applied in some machines at the same time. After such treatment a sheet having otherwise correct properties will not develop stretcher strains, provided, however, that the pressing is undertaken within about 24 hours. Beyond this time the steel reverts to its former condition, and completely so if heated, say, in boiling water, for a few minutes (5). This remarkable time effect in cold-worked soft steel was the subject of important researches (6), (7). Where the sheet has to be sent by the manufacturer to a user at a distance, therefore, it is better to despatch in the soft state, leaving the levelling operation to be carried out just before pressing.

If left in the cold-worked condition, soft steel undergoes a marked change which depends on time: that of ageing. The ductility falls and the hardness increases, and an annealing process at 650°C. is necessary to restore it. This is a process exactly similar to that of the age-hardening of duralumin and similar alloys, and is caused by the precipitation of minute particles of carbide, and probably also of nitride, from solid solution in the ferrite (8). It is claimed (9) that by suitable alterations in steel-making practice a non-ageing steel may be obtained, which neither develops stretcher-strains nor hardens on storage in the cold-worked state. As the steel is also stated to be devoid of the usual property of showing increased brittleness at a " blue heat," it would appear that its preparation is such as to prevent ultra-microscopic precipitation, to which both ageing and blue-brittleness are due. The published analyses show the presence of appreciable quantities of aluminium and titanium, so that the steel is in a fully de-oxidised condition. It may well be that improvements in steel-making practice will be the principal means of overcoming the present difficulties in the pressing of soft steel.

Sheets intended for pressing or deep drawing are not usually made from fully killed steel. It is important that they should have a smooth surface, which is preserved throughout the process of manufacture and pressing. Steels of the " rimming " class are characterised by an outer skin of ferrite almost free from carbon and from inclusions, such as sulphides. Beneath this skin is a zone of blowholes, and the inner portion of the ingot contains segregated impurities. The art in making such steel successfully consists in obtaining a sufficiently thick rim, with the blowholes at some depth below the surface. When this has been achieved, the soft surface remains clean and readily takes an almost mirror-like polish. Should the blowholes be too near the surface, blistering is liable to occur, and the surface may be badly damaged. In soft material, the blowholes, if deep-seated, should weld up during the process of hot-rolling, but if close to the surface of the ingot this will not occur, and the non-metallic impurities which accompany them are very likely to cause cracks in the pressing operations. The making of good ingots of rimming or semi-killed steel is rather an art than a

scientifically controlled process, but the work of the Heterogeneity Committee of the Iron and Steel Institute is now largely directed towards establishing scientific principles in this branch of the industry, comparable with those already accepted in the making of fully de-oxidised steels. The form and mode of handling of the ingot moulds, and the treatment of the ingots in the soaking pits, as well as the control of the conditions in the furnace, are factors of importance in this connection.

Although the quality of steel sheets depends largely on the condition of the surface, the presence of a segregated inner zone has its effects. Such a zone is appreciably harder than the ferrite, and more subject to ageing, and the outer zone frequently has much larger grains than the inner, causing defective behaviour in the pressing operations. This is especially the case where decarburisation has occurred during annealing, leading to excessive columnar grain growth in the outer layers, a cause of corrugations in some deep stampings (10).

The quantity of carbon in steels of this class is very low, usually less than 0.10 per cent. for the thinnest sheets, and only rising to about 0.13 per cent. in heavy stampings, such as wheel cups (11). The effect of different distribution of the carbide has been little studied, and perhaps insufficient attention has been given to the effect of oxygen and nitrogen. The presence of carbide at the grain boundaries is stated to accelerate ageing (12).

This paper being only an introduction to a general discussion, it is not intended to enter into the question of the best mechanical and thermal treatment to obtain the desired mechanical qualities. A given size of grain may be obtained equally well by normalising above the upper critical point of about 900°C., or by cold-working followed by box annealing at a much lower temperature, and the microscopic structure may even be identical in the two cases if favourable conditions have been selected. Normalising is usually conducted in continuous furnaces, whilst box annealing involves contact between sheets in a pack, so that too high a temperature causes a risk of sticking. It is this risk which leads to the phosphorous content of most steel of this class being maintained at a higher level than might otherwise be desirable, phosphorus diminishing the tendency to stick.

Marked differences of opinion exist as to the best means of achieving the desired grain size and texture. Severe cold-rolling followed by annealing is favoured by some, whilst others prefer to obtain the required results by normalising only. It is important to avoid reductions between 5 and 30 per cent. in thickness by cold-rolling, as annealing after this degree of reduction gives rise to excessive grain growth. With a greater degree of reduction the grain size obtained on annealing is practically independent of the amount of cold-rolling. The higher the final annealing temperature, the more completely are the directional properties of the sheet eliminated. The properties of normalised sheets are practically independent of the direction of rolling. It is often claimed that the normalised sheets have a more regular grain size than those which have been box annealed, but this will depend very largely on the conditions of annealing. Very unequal heating in the annealing box is liable to produce variations of grain size, and this defect will be the more pronounced the lower the annealing temperature used. Probably the higher the temperature the better, consistent with the avoiding of sticking.

Next to the production of a suitable grain size comes the preservation of an unoxidised surface during annealing. Throughout the whole process of heat-treatment oxidation is to be avoided as far as is practicable. This is true in the normalising process as well as in the final pickling. Although scale is removed by pickling, it is better to keep its production down to a minimum; the less work the pickling process has to perform, the better would seem to be the prospect of obtaining a satisfactory surface in the final processes. The control of the atmosphere in box annealing has received much attention, but it is probable

that considerable improvement will be made in the near future. A mixture of nitrogen and hydrogen, obtained by the cracking of ammonia gas, has been used with success (13), and on the laboratory scale this is a very suitable atmosphere for the annealing of steel without the formation of an oxide layer. These are points which, no doubt, will be dealt with in the discussion.

Stainless steels of the ductile type are finding increasing application in cold-pressing work. The metallurgical difficulties which they present are not serious. While the initial ductility is high, the alloys harden rapidly by cold-work. Steels of the 18:8 class are commonly used, but for very deep drawing a lower proportion of chromium and higher nickel, such as 12:12, is also used. Intermediate annealing has to be set at a high temperature, 900°C. to 1,000°C., and the annealing should be carried out rapidly to avoid cracking. Stainless iron, with high chromium but without nickel, requires intermediate annealing at 750°C. The great work-hardening capacity of stainless steels tends to cause increased wear on the dies, and practical modification of the pressing or drawing process has to be made to suit the peculiarity of the material.

Much less investigation has been conducted in connection with the non-ferrous metals than with steel. Pure metals are softer than alloys, and are more liable to give wrinkles, but their high ductility is an advantage. A suitable and uniform grain size is as desirable as in the case of steel, and the control of the material largely takes the form of grain size measurements. Here, also, the existence of a critical degree of deformation causing rapid grain growth on annealing is a fact to be taken into account. The practice of annealing in coils is responsible for much inequality of grain size, and probably considerable improvements in practice will become common in the near future. The American practice of issuing grain size charts has proved useful, and some modern types of metallographic microscope provide means of comparing each specimen with a standard in the course of examination.

Aluminium requires a low annealing temperature, in the neighbourhood of 350°C. Too high a temperature coarsens the grain. The alloys are harder. Duralumin and similar age-hardening alloys may be worked in the soft state, immediately after quenching, and allowed to harden afterwards.

There is little doubt that progress, especially in regard to steel, will come from a thorough investigation of the metallurgical condition of the material at each of its various stages, beginning with an improvement in ingot structure. In the subsequent operations, a principal aim would seem to be the arrangement of thermal treatments and mechanical handling in such a way as to cause the least possible damage to the surface. A good strip or sheet having been produced by hot-rolling, it is undesirable to allow this to become injured by scaling or by mechanical damage, and efforts will be directed to using such controlled atmospheres and such methods of handling as to allow the final smooth and bright surface to be produced with the least trouble.

Appendix

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NEW RESEARCHES ON THE DRAWING OF CYLINDRICAL SHELLS *

BY

G. SACHS, Dr.-Ing.†

INTRODUCTION

In deep-drawing operations connected with mass production the question of the reduction that can be obtained in a single draw without causing excessive waste is of considerable importance. This drawing capacity (maximum draw) has, as will be obvious from Fig. 1, proved capable of very considerable increase

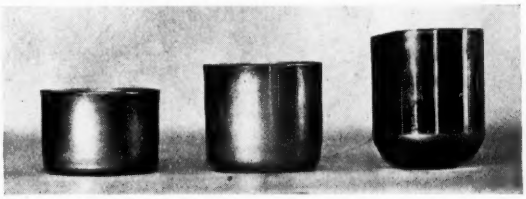

FIG. 1.

in the course of the last decade. Whereas, according to Walter Sellin,‡ formerly a brass blank of dia. D could only be converted into a shell of dia. $d=0.6\ D$ and of height $h \simeq 0.75\ d$, and not till 1930 was it possible to produce a shell with $d=0.5\ D$ and $h \simeq d$, for several years now shells have in practice been produced in a single draw having $d=0.4\ D$ and $h \simeq 1.3\ d$.

The remarkable increase in saving that this implies is due mainly to the fact that skill has been attained in imparting to the required material the deep-drawing sheet, when preparing it, such qualities that, in consequence of the uniformity of its properties, texture, thickness and surface, the material can be utilised without residue. The author does not propose, however, to discuss this matter further in this paper.

On the other hand, from systematic investigations made in practice and in scientific laboratories, the great importance of the operating conditions on obtaining reductions as great as possible has come to be recognised. Practically every individual feature of the tool form, in Fig. 2, and of the machine arrangement exercises a certain effect on the drawing capacity, and this to an extent depending on the working material, sheet thickness and size of the flange. In spite of these complications, the manner in which the various factors co-operate, more especially in deep-drawing, has been, in great measure, cleared up by a series of fundamental researches—at least for the simplest case of the first draw of round blanks.

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* A paper read at a joint meeting of the Institution of Automobile Engineers, the Royal Aeronautical Society, and certain other Technical Institutions and Societies.

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‡ See Appendix for references throughout the paper to other published works.

Drawing Without and With Sheet-Weakening (Deep-drawing and Ironing)

Of fundamental importance on the entire process is, primarily, the size of the clearance between the punch and the die. During the drawing operation the edge of the flange becomes steadily thicker, the thickness increase being roughly 40 per cent. (2) with a reduction of $d/D=0.5$. The clearance must therefore be

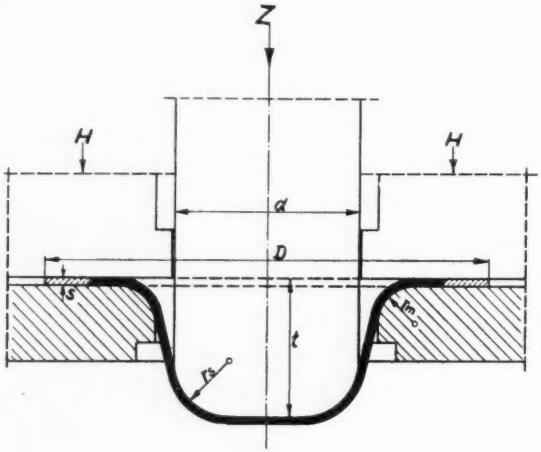

Fig. 2.

roughly 1.4 times as great as the sheet thickness if the sheet is to slide through, without hindrance, during drawing. Otherwise a second process is superposed on the deep-drawing proper, which corresponds, in principle, to ordinary tube-drawing. In the load diagram, Fig. 3, this is, according to the investigations of

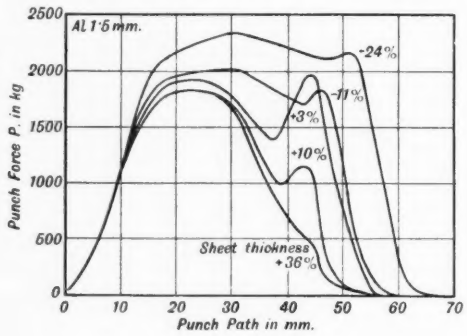

Fig. 3.

the author (2), shown by the fact that a second working area is superposed on the drawing diagram proper, with gradually diminishing clearance and that, finally, the two coincide. Such an operation, with a narrow clearance, is designated "drawing with sheet weakening" (thinning of side walls) or "ironing." The researchers have, so far, been almost exclusively concerned with the simpler process in which the clearance is at least so large that the second operation is of little importance. This is according to Fig. 3, the case

with a clearance that is approximately 5 per cent., or more, larger than the metal thickness.

Tool Form and Drawing Capacity

In such deep-drawing, pure and simple, the capacity for drawing is, to a great extent, dependent on the form given to the tool. Taking the case of a die and a punch having plain working surfaces and circular transition, then according

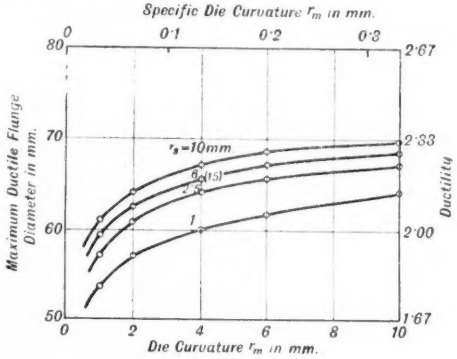

FIG. 4.

to the researches of Walter Sellin (3) and also of Herrmann and the author (4), as illustrated in Fig. 4, the drawing capacity increases both with radius of curvature of the die (draw edge radius) and also that of the punch. Furthermore, the maximum capacity is attained at a greater radii the thicker the sheet. It is thus of primary importance, more especially with thick sheet metal, that the tools should be well rounded off, if large first draws are to be obtained.

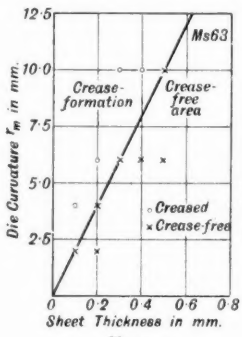

FIG. 5.

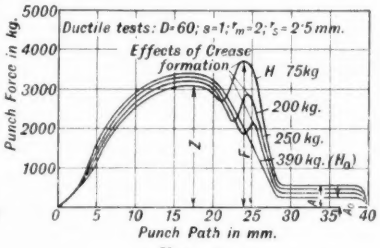

FIG. 6.

The curvature of the punch r_s must not, as the investigations of Herrmann and the author have shown (4), exceed a definite upper limit, represented by 0.3 of the punch dia., as otherwise a premature breakdown of the shell will take place at the curved edge of the punch (see Fig. 8).

The maximum admissible value for the die curvature r_m is, on the other hand, determined by the condition that, with the ordinary form of blank holder with plain surface as illustrated in Fig. 2, the drawn flange is held for only a brief time and thereafter creases. This creasing constitutes really a buckling problem which has also been investigated theoretically by Geckeler (5). The

formulæ, however, which determine the formation of creases as dependent on the drawing conditions, have not yet been developed far enough to enable practical inferences to be drawn. From the experimental results obtained by Herrmann and the author (4), as reproduced in Fig. 5, it appears that with brass, for example, the die curvature must not be greater than 20 times the thickness of the sheet. This figure should be valid for a great number of other materials also; in the case of materials having a tensile strength that is high relatively to the modulus of elasticity, the die radius should not be so large, in accordance with the general laws governing buckling.

Blank-holder and Drawing Capacity

The drawing capacity, further, depends, to a considerable extent, on the form imparted to the blank-holder and the way in which it is pressed on the flange. The determining factor is the pressure H at the moment of the maximum drawing force, see Fig. 2. The greater the pressure, the higher this drawing force becomes, as shown in Fig. 6, and the smaller is the drawing capacity. On the other hand, Fig. 6 shows that the blank-holding pressure must not fall below a certain minimum value, as otherwise creases are again formed, as in Fig. 7,

Fig. 7.

which render the shells unfit for use. The favourable case in practice occurs when the pressure on the holder is always great enough to suppress the formation of creases. Exact researches carried out by Herrmann and the author (4) have proved that this favourable blank-holding pressure depends, to an extent which cannot be neglected, on the drawing conditions, and, more particularly, increases rapidly as the curvature of the die increases and the sheet thickness diminishes. With a favourably formed tool, however, for brass and steel, a specific blank-holding pressure of 10-12 kg. per sq. cm. on the flange surface below the blank-holder is obtained, *i.e.*, approximately 1/200 of the sum of the tensile strength and yield point, and this pressure is sufficient to suppress the formation of creases.

In the case of sheets that are thicker than 3 per cent. of the punch dia., such holding pressures and even substantially higher ones have hardly any effect on the drawing capacity. The thinner the sheet, the more harmful, however, is the effect of the holding pressure.

To ensure that the latter is maintained at the correct level use is being made, to an increasing extent, of pneumatic and hydraulic blank-holders. In the rigid blank-holders formerly in vogue, on the other hand, the pressure may, when the adjustment is incorrect or the sheet is of non-uniform thickness, reach a very high degree, and even flexibly-mounted holders enable the holding pressure to be regulated to only an inadequate extent. In the case of rigid blank-holders, however, the holding pressure may, according to Linicus and the author (7), be reduced, in practice, to zero if the holder is constructed of conical form. The bearing surfaces must be so smoothly ground as to allow the sheet to thicken without hindrance during the drawing; in other words, the distance between the blank-holder and the inner edge must increase by about 30 per cent. of the sheet thickness.

Stresses and Strains in Deep Drawing.

In what precedes, the influence of several of the most important factors

affecting the operation of deep drawing has been explained. At the same time, the fact remains that in order to obtain an adequate understanding of the effects of these various factors and of their extremely complicated inter-action, it is necessary also to have gained a comprehensive insight into the internal forces at work, namely, into the stress and strain conditions. Scientific investigations conducted during the last 10 years have greatly contributed to elucidate these points.

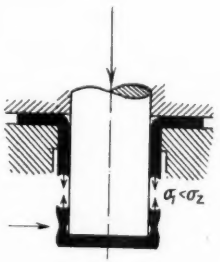

FIG. 8.

As shown in Fig. 8, the success of the drawing operation depends solely on whether or not one condition is satisfied, namely, that the drawing force per unit of surface σ_1 (wall stress required to draw) throughout the drawing operation must always be smaller than the breaking strength σ_z.*

As regards the breaking strength, the first obvious suggestion is to put this equal to the ultimate tensile strength σ_B of the working material. This assumption is, however, completely erroneous, as is clear from Fig. 9. According to

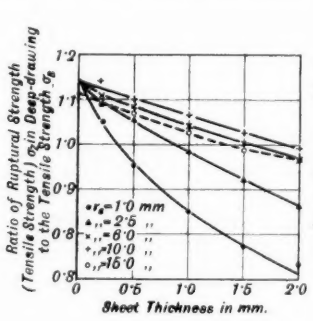

FIG. 9.

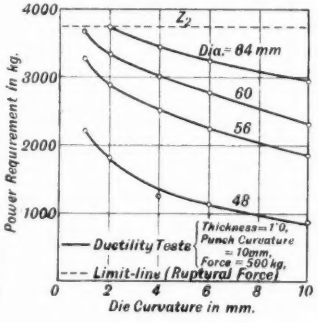

FIG. 10.

the investigations of Herrmann and the author (4) conducted on brass and 18/8 steel—and, therefore, most probably in the case of all materials—the breaking strength falls off rapidly with the sheet thickness s and the punch curvature r_s, in accordance, approximately, with the following equation:—

$$\frac{\sigma_z}{\sigma_B} = 1.14\left[1 - \left(0.7 + 1.8\,\frac{r_s}{d}\right)\frac{s/r_s}{2 + s/r_s}\right]$$

This equation holds good up to an upper limit value of $r/_s d \simeq 0.33$, where the breaking strength reaches its maximum value.

$$\sigma_{max} = 1.14\,\sigma_B\left[1 - 1.3\,\frac{s/r_s}{2 + s/r_s}\right]$$

* Where weakening of the sheet occurs in drawing, it must be taken into account, because, in addition, there are frictional forces set up between the shell and the die or the punch.

In this way also—as already stated above—the most favourable form for the punch curvature ($r_s \simeq 0.33\,d$) is also determined.

The increase in the breaking strength as the sheet thickness is reduced and the die curvature decreases, until it becomes 1.14 times the value of the tensile strength, can be explained as follows:—The shell is a tube subjected to tensile stress, any reduction in the diameter of which is prevented by the punch. If the same conditions be set up by hydraulic internal pressure, then the yield point and also the tensile strength of such a tube are, according to the investigations of Lode (8) and others, roughly 1.16 times as great as those of a solid bar or a tube (without internal pressure) consisting of the same material. A sharp punch curvature will then tend to reduce the breaking strength still further inasmuch as it exerts normal pressures on the sheet surfaces. This reduction must, from theoretical considerations, be proportional to the ratio of the sheet thickness to the punch curvature, and this is, in point of fact, the case, but no exact estimate of its amount is so far available.

The maximum value of the tensile load or stress, on the other hand, diminishes rapidly with increase in the die curvature (4), as is shown by Fig. 10 for example. The exact conditions as to this are still very obscure; the effects of the sheet thickness, of the material itself, etc., have so far not been definitely studied.

None the less, the theoretical investigation of the drawing process, which gives a valuable insight into the operation, has been devoted, more particularly, to the drawing force. The assumption underlying this procedure is that this latter force can be split up into a number of component parts:—

1. The drawing force proper, which produces the strains under the blank-holder ($=\sigma_0 \cdot 2\pi Rs$).
2. The flexural or bending force around the die curvature ($=B$).
3. The frictional force opposing the blank-holder pressure (coefficient of friction $=\mu$).
4. The frictional force impeding motion over the die curvature.

This splitting up is, however, arbitrary, more especially as regards the differentiation between the tractive and bending forces proper, and is, most probably, in approximate harmony with the actual conditions, for small die curvatures only. The earlier investigations, however, show that this condition is approximately complied with.

Through the first researches of Sommer (9) and Eksergian (10) bearing on the calculation of the drawing force, the different component elements were definitely established.* At the same time, no satisfactory estimates can be deduced from their researches, inasmuch as they make false assumptions, more especially as regards the conditions determining plasticity in metals. The drawing force proper was then calculated by Siebel on the basis of the possible plasticity condition, according to which the maximum shearing stress is constant. The actual stress conditions within the blank are the same as in a thick-walled tube subject to internal pressure.

The author (2) has accordingly, by making use of this condition, undertaken an elaborate calculation of the drawing force. Employing the reference designations seen on Fig. 11, the following differential equation is obtained for equilibrium between the forces acting on an annular element of the blank of volume $f \cdot dR = (R \cdot \gamma \cdot s.)\,dR$:—

$$d\,[R \cdot \gamma \cdot s \cdot \sigma_1] - 2\sigma_3 \cdot dR \cdot \gamma/_2 \cdot s = 0$$
$$d\,[\sigma_1 R]\,/dR = \sigma_3.$$

* The agreement between theoretical calculation and experiment in Sommer's case must therefore be regarded as accidental or else artificially arrived at.

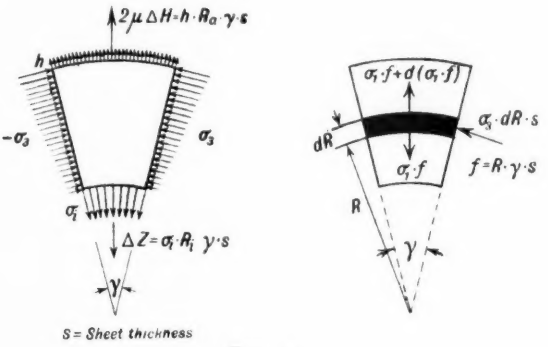

FIG. 11.

As a condition of plasticity, however, the shear stress condition ($\sigma_1 - \sigma_3 = k$) is not valid here; but, in accordance with more recent advances (8) (12), the shear stress must be estimated at 15 per cent. higher, averaging, therefore, roughly

$$\sigma_1 - \sigma_3 \cong 1.10\, k.$$

Hence the drawing stress proper is first obtained by integration, as:—

$$\sigma_0 \cong 1.10\, k \,.\, \log_e \,.\, \frac{R_a}{R_i}$$

(where R_a denotes the outer radius and R_i the internal radius of the annular portion below the blank-holder). This would therefore be the expression for the drawing force, if only the resistance k of the material had to be overcome and provided no frictional or flexural resistances occurred.

When, however, the other components—blank-holder friction—(μH on the outer edge), friction on the die curvature (factor $e\mu\,\pi/2$) and flexural force (B, the calculation of which is still wanting), the drawing force becomes:—

$$P = e\mu\,\pi/2\left[2\pi \,.\, R_i \,.\, 1.10\, k \,.\, \log_e \,.\, \frac{R_a}{R_i} + \mu H \,.\, \frac{R_i}{R_a}\right] + B.*$$

This value must be calculated separately for every stage of the drawing process. The quantity k must be taken as the mean value of the stress given by a stress-strain curve corresponding to the actual behaviour of the material.

For purposes of comparison Fig. 12 shows several drawing force diagrams calculated according to the foregoing formula (the flexural forces being ignored) and several diagrams made out from experimental tests. The discrepancies in the ordinates may be accounted for by the ignored flexural forces and the

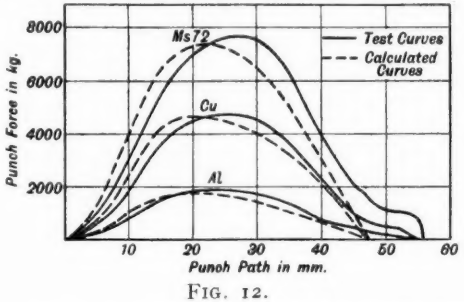

FIG. 12.

* For the beginning of the drawing process, when the shell is still conical, the formula becomes even more complex.

differences in position by the neglect of the additional deformations occasioned in deep drawing.

The author (4) has, by making use of data provided by Lode (8) relating to the general relationships between stresses and strains, succeeded to a great extent in calculating the deformations also. In further researches by Draeger (13) and also by Herrmann and the author (4), the exact manner in which the surface area of the shell depends on the various factors incident to the drawing process has finally been cleared up.

Testing of Sheet Ductility

Up to within a few years ago it was believed possible to test the suitability of a metallic sheet for deep drawing by simple mechanical trials. More especially the Erichsen cupping test, and other tests, which are easy to carry out and provide a test specimen similar to the shell produced by drawing, are extensively employed even to-day for sheet testing. More exact investigations by Siebel and Pomp (14), as also by Dörge (15), have, however, shown that the cupping test gives what is essentially only a substitute, which is difficult to determine, for the extension in the tensile test.

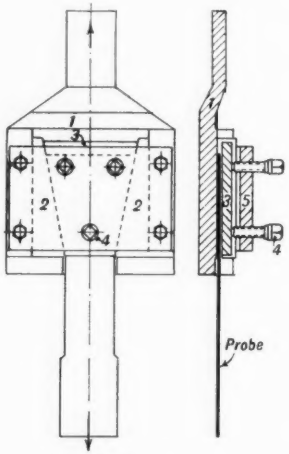

Fig. 13.

Wedge-drawing apparatus.

1 = Baseplate.
2 = Side wedge.
3 = Tensioning wedge.
4 = Tensioning screw.
5 = Cover.

The lack of agreement between the results from drawing and cupping tests has led, further, to proposals and even to apparatus for the determination of deep drawing capacity in a form as simple as possible and divested of too elaborate practical operation. Tests carried out by G. R. Fischer (16), Kummer (17), Eisenkolb (18), F. Fischer (19), Kühner (20), and others have, indeed, demonstrated that with simple laboratory equipment conclusions may be drawn regarding deep drawing of equal value with those obtained from technical experiments. As a result of this knowledge, practical apparatus which can be easily manipulated has been provided, such as the deep drawing tester of Wazau (4) (21) and the cupping accessory to the Erichsen apparatus (22). These are also eminently suitable for scientific investigations in deep drawing.

The attempt to obtain, with more simple means, knowledge of equal value to that obtained from actual drawing has led to the wedge drawing apparatus of the author (2), which is reproduced in Fig. 13. The identical idea has sprung up independently in America (24). From several experiments made by Bauer, Weerts and Beck (25) on zinc, and more particularly by Kayseler (26) with a more elaborate type of apparatus on steel, the utility and feasibility of the new test may be considered proved. According to Kayseler (26), such tests also (in somewhat modified form) enable conclusions to be drawn regarding the exhaustion of the ductility during the drawing process.

In this connection mention must be made of still more recent attempts to determine the ductility of a thin sheet of metal. The classical attempt in this field is the reciprocating bend test, which, however, yields diverging and rather unintelligible results (27, 28) depending on the experimental conditions. Siebel and Pomp (29) have accordingly indicated a fresh test for the ductility of sheet metal. In this test a previously perforated sheet is punched by a cylindrical punch. The aperture widens out and finally splitting occurs; the widening provides a measure of the ductility. The utility of this test is confirmed by Cournot (30) and Fournier (31). From investigations made by the author (32) the ductility may be determined in a still simpler manner by employing a conical plug as punch in the Erichsen apparatus. In such an experiment, what happens first is that a circular cap (calotte) peels off; the depression in this case corresponds to the ordinary depression. As the punch is forced in farther the edge of the bore tears; the depression in this case corresponds to the widening in that of Siebel and Pomp.

Outlook

The researches so far available provide, therefore, a fairly complete account of the behaviour of the working material in the simplest case of deep drawing, the drawing of cylindrical shells in the first operation. Reference has already been made above to a number of gaps in the knowledge of the whole subject which are still waiting explanation by experiments and theoretic researches.

With regard to the more complicated cases of deep drawing, such as:—

(1) Drawing with sheet weakening (ironing),

(2) Drawing of irregularly-shaped bodies, and

(3) Drawing in subsequent operations (re-drawing),

practically no research work has, so far, been undertaken, from which any serviceable insight into these operations might be gleaned.

Drawing with sheet weakening is, as already mentioned, a process closely allied to that of tube drawing. Certain hints as to how this process should be investigated may therefore be extracted from the more recent treatises dealing with tube drawing, such as those carried out by Pomp and Albert (33), of Pomp and Schylla (34), as also by Jung-König, Linicus and the author (35).

Regarding the power consumption in drawings necessitating two or more operations, several experiments have been carried out by Goederitz (22) with the new Erichsen apparatus. No analysis of the process is, however, available so far.

The further problem also as to how many draws a material can withstand before it becomes brittle and must be annealed has, so far, not been accurately studied. The experiments of Kayseler (26), referred to above, have proved in the most remarkable manner that steels subjected to different treatments lose their ductility—measured by the Erichsen depression—with varying degrees of rapidity, while gaining additional strength in the drawing. These experiments explain why it is that the prior history of the material—at least, in the case of steel—is of very vital importance on its behaviour during deep drawing.

The condition of the material is in turn of a distinct importance in the estimation of its deep drawing capacity, and it should be remembered that it is not the case that the fully annealed condition is, in every instance, the most favourable one. Both the theoretical researches of the author (2) and also the experiments of Eisenkolb (18) on steel have confirmed the fact already well known in practical working, that slight cold working has a favourable effect on the ductility. In the case of steel there is the further advantage that, when this method is adopted, the disturbing flow figures noticeable at the highly strained positions on the bottom, and on the punch curvature, disappear.

Lastly, from certain investigations it appears that adequate lubrication and proper conditioning of the surfaces are stipulations that should be emphasised. Any exact data on the undoubtedly considerable influence of these factors are, however, not yet forthcoming.

In conclusion, reference may be made to an occurrence that may be highly detrimental to satisfactory drawing and that is the formation of ears (*i.e.*, tips or excrescences). As a result of a series of elaborate researches carried out by Kaiser (36), Göler and the author (37), Phillips (38), Bassett and Bradley (39), and others, it has been ascertained that this effect is due to a parallel stratification of the crystals in the sheet texture, occasioned by unfavourable treatment in the rolling and heating processes. In these articles methods and means are also prescribed whereby, through proper selection of the material and of the working conditions, this ear formation may be obviated.

Appendix

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THREE PAPERS ON "COLD PRESSING AND DRAWING"

BY

(a) H. J. GOUGH, M.B.E., D.Sc., F.R.S., and G. A. HANKINS, D.Sc.

(b) C. H. DESCH, D.Sc., F.R.S.

(c) G. SACHS, Dr.-Ing.

Discussion

Sir Harold Carpenter (Chairman): He would ask Dr. W. H. Hatfield to open the discussion, but first he would offer him their warmest congratulations on the honour recently conferred upon him by the Council of the Royal Society in recommending that he should be elected to its Fellowship. It was about 30 years ago when Dr. Hatfield "came over the metallurgical horizon," and those who have followed his work since, in its many applications, feel that the honour is very well deserved.

Dr. W. H. Hatfield: He had no essential criticism to make of any of the facts stated in the papers; they had been presented admirably. He could merely offer one or two illustrations. He thought it must be conceded that the Brinell test, the small ball or Erichsen test, have been great standbys for those engaged in the plastic deformation of metals, but it is also true to say—leaving the Brinell test, a general indication—that the Erichsen test is not and cannot be a final valuation of the capacity of a metal for plastic deformation in these pressing and drawing operations. Undoubtedly the form of test which Dr. Gough and Dr. Hankins have described to-night gives a definite advantage. As Dr. Gough has said, it gives stress-strain relations, but even so, and this is a difficulty, no laboratory test can really hope, in his opinion, to construe successfully the complex conditions which have necessarily to be dealt with in many drawing operations. A delicately performed tensile test, properly understood, does give adequate knowledge of the capacity of a material for plastic deformation and of the manner in which such material is likely to perform—with the reservation that something must be known of the microstructure, the size of crystal grain, as Dr. Desch has pointed out, and also of the quality of the surface. To his mind, progress in cold pressing operations will be determined entirely by an improvement in the control of the microstructure and an improvement in the surface of the sheet or strip—and, of course, to deal with both these points necessitates great care and very materially increased costs. There is no doubt that to get, under practical conditions, anything like the degree of plastic deformation which is possible with stainless steels and non-ferrous metals it will pay those in Industry hands down to encourage the producers of metal to take the extreme steps necessary to comply with the theoretical conditions laid down this evening. He could not emphasise too strongly what Dr. Desch has said in the concluding paragraph of his paper that "A good strip or sheet having been produced by hot-rolling, it is undesirable to allow this to become injured by scaling or by mechanical damage, and efforts will be directed to using such controlled atmospheres and such methods of handling as to allow the final smooth and bright surface to be produced with the least trouble"—and, one would add, in the most perfect state. From his experience, which is quite considerable in

this field, this seemed to him to sum up the matter; and the disability of such tests as the Erichsen and of the more advanced type of test which Dr. Gough and Dr. Hankins have put forward is, in the first place, that they do not reproduce the practical conditions. They necessarily use a specially prepared piece of steel, whereas the man engaged in pressing has to take the sheet or strip and use it as it is. They do not take notice of a very interesting point which he wanted to illustrate.

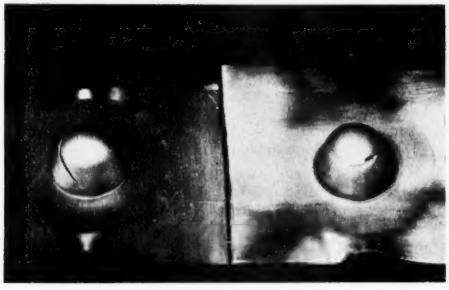

FIG. 1.

FIG. 2.

Fig. 1 shows the results of two Erichsen tests on austenitic rustless steel. In the first the surface of the hemisphere produced by the Erichsen test is perfectly smooth (visually), and in the second the orange peel effect to which Dr. Desch has referred, is noticeable. Fig. 2 shows the microstructure of the sample which gave a smooth surface, and Fig. 3 illustrates the microstructure of the sample having the coarse surface. That problem has been dealt with for some years and the size of crystal is controlled with great advantage, because it is obvious that if the coarse orange peel effect is developed in pressing, it means, in the first place, if the metal has to be polished, that very greatly increased expenditure

has to be faced; and also there is the disability of not having a smooth surface for paint or cellulose, etc.

But there are some very interesting figures which he would like to point out to Dr. Gough. It is known that with a crystal aggregate of the same material with very small crystals, the elastic range is higher than in the case of an aggregate consisting of a much smaller number of larger crystals. The result is, therefore, that under the Erichsen test, curiously, a lower value is obtained with a very small crystal structure having the higher elastic range

FIG. 3.

FIG. 4.

than with the coarse crystal structure and the lower elastic range. Yet the users of these metals virtually say: "Give us the material with the smaller crystals, having the higher elastic range." There is an instance of a definite and well-explained instance in which even Dr. Gough's test, with its improvements, must fall down in the same way, because the size of the crystal and the surface of the sheet must be taken into consideration.

He would not say more about the surface of the sheet, because the importance of that is so obvious. The higher the quality of the sheet as disclosed by visual examination from the scale point of view, and by the microscopic examination, the better will be the results.

Fig. 4 illustrates a case that has come to his notice during the last few years. It is a beautiful example of the cracking of a pressing produced in austenitic rustless steel in one operation. It came to him in perfect condition, uncracked, about ten years ago, and was placed on his laboratory mantelpiece. After some time he noticed that it had cracked and all the cracks seen in the illustration developed over a period of about three years. Clearly the pressing has not been annealed. The Brinell figure was about 400; the plastic deformation had produced such hardness. An interesting factor is that there were no corrosion effects. In the season cracking to which Dr. Desch has referred there is the effect of the slight content of ammonia in the atmosphere, for example, as established by Dr. Moore, but in the case of this pressing the non-corrodible condition is present, and the passive film which he believed remains perfect under these conditions. He believed the trouble is due to the cold work and superposed upon that the normal variation of temperature in an office due to heating and to weather changes. The appearance of these cracks emphasises the great importance of the measure of plastic deformation which can be safely applied to a metal.

Dr. H. W. Brownsdon: Dr. Gough, in the opening of his paper, reviews the subject broadly and suggests five headings under which the problem involved might be conveniently discussed. Three of these have been so fully dealt with in the papers submitted that he proposed drawing attention to some of the difficulties encountered both in the manufacture of the material and its subsequent drawing.

The manufacturer of deep pressings or drawn products demands a material which will permit him to produce the finished product in as few operations as possible, and in order to do this it must conform to the three requirements of high general elongation, small crystal size and uniformity, conditions not easily satisfied in bulk production. As a criterion of these desired properties, a cupping test is both the simplest and most informative, elongation being related to the depth of the cup, crystal size being revealed by the appearance of the dome, and uniformity by the results obtained on testing bulk deliveries. The manufacturer has to control the composition of the metal, its subsequent rolling and annealing treatments, so as to obtain in the finished strip or sheet the maximum depth of dome associated with a grain size sufficiently small to make subsequent polishing an easily and rapidly carried out operation. Confining his remarks to brass, ± 0.5 per cent. of copper reflects itself in the cupping test, especially if the alloy be on the border line of the alpha, alpha + beta phases. Small variations in impurities are also disturbing factors. Equally important are rolling reductions and the time-temperature conditions of annealing. This latter operation is influenced by composition, by small variations in thickness and by the surface condition of the strip, especially important in continuous annealing, since a bright clean surface absorbs heat from the furnace much more slowly than a dull surface. With all these variables coming into play the finished product rarely exhibits the optimum combination of desired properties, these being the resultant of a number of disturbing factors.

As regards pressing and drawing operations, a number of basic principles can be formulated, but when it comes to the drawing of different metals, difficulties may be encountered which are not associated with the mechanical properties or uniformity of the material. One of the most important conditions to be satisfied in deep cylindrical drawing operations is that of adequate lubrication, not only to prevent wear of the die, but also scoring of the products, which may occur if the surface of the die becomes fouled with the metal being drawn. The fouling of a drawing die is not dissimilar to the seizing of a bearing and may soon lead to serious trouble; the press may stall or the bottom of the product be knocked out. Several factors are involved, including the metal to be drawn, its surface condition, working surface of the die, lubricant, speed of drawing, and the amount of work being done, temperature being dependent on all these factors, whilst the

concentration of work will be influenced by the contour of the die, which determines the area over which the drawing load is distributed. Different metals behave differently in their tendency to foul the die. Zinc, a very ductile and soft metal, readily fouls steel dies, which may be due to the high surface temperatures involved in rapid drawing operations facilitating a type of galvanising action leading to fouling. Cupro-nickel is a soft ductile alloy, prone to fouling of the dies. In this case the trouble is most marked with freshly pickled and cleaned metal and frequently disappears if the metal is allowed to stand exposed to the atmosphere for several days. Such a change in behaviour may probably be due to the formation of surface oxide films which prevent bare metal-to-metal contact during drawing. The value of a slightly tarnished surface as a preventative against fouling may even make itself evident in the drawing of 70/30 brass. Aluminium bronze is another alloy which readily fouls the die, this perhaps being due to surface films of abrasive oxide.

The fouling of the die is most marked where the base of the product supported on the punch first strikes the die and under the heavy and rapidly applied load over a small area the film of lubricant undoubtedly breaks down.

Lubrication of the product and die during drawing operations presents a number of interesting problems. The work done is heavy and the area on which it is done is small and there is therefore considerable generation of heat and the lubricant must also play the part of a coolant.

Some lead in the choice of suitable lubricants can be obtained from so-called wear tests in which the periphery of a loaded revolving hardened steel wheel is run in contact with the metal to be drawn, in the presence of a lubricant. The wear as represented by the volume of metal removed varies considerably with different metals, using the same lubricant, as well as with the same metal using different lubricants, and under sufficiently heavy loads the breakdown of the lubricating film can be observed by a fouling of the periphery of the steel wheel and scoring of the metal being tested. In this way the suitability of soap solutions for the drawing of 70/30 brass and its unsuitability for the drawing of aluminium bronze may be established, the aluminium bronze fouling the periphery of the steel wheel under load at which brass is perfectly lubricated.

When serious die fouling difficulties are met with they can be overcome by coating the metal to be drawn with a thin layer of non-fouling metal. An aluminium bronze product coated with copper, for example, draws readily without die fouling troubles. The use of what might be termed a metallic lubricant has other important features, as it may permit of heavier drawing reductions and fewer intermediate annealing operations, as in the case of the " Dudzeele Process " for drawing steel tubes, the tubes being coated with lead.

Mr. G. C. Richer: He was speaking from the point of view of the manufacturer of deep-drawing sheet steel, but he did not propose to accept the rather subtle invitation of Dr. Gough to expand on the problems associated with its manufacture—it would take too long, and really demanded separate treatment. He proposed, therefore, to confine himself to the potentialities of a modified Jovignot fluid-pressure cupping test as investigated at the N.P.L.

Every manufacturer of deep-drawing sheet metal would welcome any test which could be accepted as indicating, with a reasonable degree of certainty, the suitability of a given material for deep-drawing operations. He was a little doubtful, however, whether it is actually possible to devise any one simple form of test which will conclusively indicate whether a given material is, or is not suitable for deep-drawing by modern rapid-action power presses.

The chief troubles to-day are very well exemplified by the four samples of " mild steel sheet " referred to in Dr. Gough's paper—FVN 1 and 2 and FWN 1 and 2. Judging by the results of the tensile tests and of all the cupping tests, and the stress-deformation curves, three of those samples should give, according to all known standards of reference, quite good results in deep pressing,

while one of them would most certainly be expected to give poor results. But it is reported that two of the three samples which should really have given good performance at the press actually behaved badly, and that is typical of the more serious problems of to-day.

During 1934, the output of deep-drawing sheet steel of his firm at Newport was approximately 50,000 tons, but the number of complaints received from the press shops was gratifyingly small, and the claims made in respect of faulty material covered less than one-fifth of 1 per cent. of total deliveries. That justifies the claim that reasonably satisfactory routine methods of testing have been established, but difficulties of the type exhibited by the four " mild steel " samples enumerated by Dr. Gough are undoubtedly still experienced. There are still quite a number of cases in which they themselves obtain good testing results, which are confirmed in the press shop testing rooms, but which are *not* confirmed in actual press operations. Everybody is puzzled, and nobody seeks to blame anybody else. What is really happening?

He thought that the whole trouble resided in the fact that in most actual press operations the material is not subjected to a simple tensile strain. Many other things are going on, some of them still quite obscure, and he suggested that a simple tensile test, no matter whether it be in the form of an improved fluid-pressure cupping test or any other form, is never likely to give what practical experience indicates is the complete information necessary to establish whether or not the material under test is really suitable for *all* types of deep-drawing operations.

Some of those operations are simple, but others are complex. Alternate tensile *and* compressive strains are in so many cases imposed upon the material that is being " drawn," and both Dr. Desch and Dr. Sachs, in their papers, and Dr. Hatfield in his remarks have referred to a point that the speaker's own experience confirms is of extreme importance—namely, the necessity of arriving at some satisfactory form of test, in addition to the ordinary tensile test, which will give with some degree of numerical certainty a " figure of merit " for the rate of " strain-hardening " of the material.

With the ordinary tensile characteristics and some reliable measure of the rate of strain-hardening taken together, data might possibly be arrived at which, if anything did go wrong at the press, would enable it to be stated positively that it was not the fault of the material. But up to the present that degree of testing precision has certainly not been achieved, and although the fluid-pressure cupping test devised by the N.P.L. undoubtedly represents a great advance on any other form of cupping test previously known, he did not think that this test by itself will indicate all that is required.

The N.P.L. test has the great advantage over the ordinary tensile test in that it eliminates the special preparation of test material either by shaping or milling. Will Dr. Gough state, however, exactly what time this test occupies in reasonable operation, and what, in his opinion, is the practical everyday capacity of the N.P.L. machine in the testing of deep-drawing sheet steel? Has it the necessary strength to test deep-drawing sheet steel at the rate of, say, 100 tests every eight hours? For everyday testing a machine which is " fool-proof " is required.

Dr. Gough says that in dealing with the " ferrous " materials he had considerable difficulty in obtaining " satisfactory " and " unsatisfactory " samples for comparative purposes for his cupping tests. He took that as a compliment to the manufacturers of deep-drawing sheet steel in this country! Should Dr. Gough wish to continue his investigations however, then they would be only too glad at Newport to co-operate by producing unsatisfactory material for him by request!

Finally, it may be of interest if he briefly indicated the testing methods in use at Newport. In the first place, the Erichsen test is employed as a continuous

check, in addition to pyrometer control, on the efficiency of operation of their normalising furnaces. This test is regarded purely as an " indicative " or " exploratory " test, and he suggested that the term " confirmatory," which is used in Dr. Gough's paper, might well be amended. Reliance is chiefly placed on ordinary tensile tests, taken on longitudinal and transverse samples, coupled with an autographic stress-strain chart on each sample. As complete an indication as possible is therefore obtained of the plastic characteristics of the material under test.

Mr. J. C. Arrowsmith (*communicated* and read by Mr. Gillott): The assessment of the drawing properties of sheet material in terms of laboratory or workshop tests has been a problem from the commencement of cold press work. Many have at some time been inspired with the desire to evolve some simple test which gives a direct indication of drawing properties, but the results given in the paper by Drs. Gough and Hankins show very conclusively that no *single* test as yet provides the desired information.

If from Tables IV and VI the deep drawing mild steels are picked out, all of which are approximately the same thickness (0.040in.), together with the examples of soft copper, soft 70/30 brass and soft 80/20 cupro-nickel of the same thickness as the steel, the following apparent anomalies are found:—

1. Copper with a much lower ultimate strength and higher elongation shows a lower fluid pressure test and much lower K.W.I. test than steel, whilst the Erichsen, Guillery and A.E.G. test are the same as for steel.

2. Brass with an ultimate strength equal to that of steel and a very much higher elongation shows much higher Erichsen, Guillery and A.E.G. tests than steel, whilst the fluid-pressure test and the K.W.I. test are approximately the same as for steel.

3. Cupro-nickel with the same ultimate strength as steel and with higher elongation and Erichsen values possesses an inferior fluid-pressure test.

No one would deny that these four materials possess very different " drawing properties."

It would have been interesting to have had the corresponding test figures on examples of the deep drawing austenitic stainless steels, as these represent yet another distinct type of material. With a yield point of the order of 15 tons per sq. in. and an ultimate strength of 50 tons per sq. in., together with an elongation of 50 per cent., these steels possess exceedingly good drawing properties and require quite different die conditions from either brass or mild steel. It is interesting to note that Dr. Sachs suggests that results which hold good for brass and 18/8 stainless steel probably apply to all classes of material.

A consideration of the values of the various test results, together with their behaviour in industrial press work, of five widely different materials, such as mild steel, copper, 70/30 brass, 80/20 cupro-nickel, and 18/8 stainless steel, should at least provide lines of thought for further research. It seems significant that 70/30 brass should give results in the fluid-pressure test and the K.W.I. test no higher than those obtained on mild steel. It is possible that the rate of work-hardening or even the ratio of this property to the ultimate strength may have a bearing on these results.

It does appear from the three papers that there is still a definite need for research into the fundamental properties of metals, which may have a bearing on their behaviour in cold pressing operations. Very little work has been done on the effect of deformation at the high speeds met with in commercial practice. Winlock and Lavergne, in U.S.A., have shown that in certain types of steel premature failure was brought about when the rate of extension exceeded 10in. per min. This speed is low compared with the speed of the punch when it makes contact with the sheet in some of our automobile body panel press operations.

Another interesting feature which is brought out is that both the Jovignot and K.W.I. tests are apparently much more discriminating than the other forms

of cupping test, and that these two tests should be investigated further in connection with material whose practical performance is known. The K.W.I. test apparently gives remarkably consistent results in spite of the fact that the condition of the edge of the hole might be expected to be extremely critical. This test, incidentally, provides a very close parallel to a common press operation in the automobile industry, *i.e.*, the formation of window pockets, door openings, etc., after piercing a drawhole in the centre of the portion of the sheet to receive the depression.

A completely informative test making use of a test piece which could be produced cheaply and rapidly would be warmly welcomed in the sheet metal industry. The Pressed Steel Co. makes use of the tensile test because it is felt that yield point, ultimate strength, and both local and general elongation figures all have a bearing on drawing properties, and that they provide a much more complete picture of the material than any of the simpler ductility or hardness tests. The great disadvantage of this method is the time taken in the preparation of test pieces.

The correlation of drawing properties with physical test results would be comparatively simple if there were always a sharp dividing line between material which would perform 100 per cent. satisfactorily and material which produced 100 per cent. failures. It is a much more difficult task to produce test results to account for a difference between material performing with a nominal 1 per cent. scrap and material resulting in the irregular production of 10 per cent. scrap. Such a difference might be accounted for by a general lower standard of ductility in the material, resulting in the material accommodating itself less successfully to slight variations in die conditions, or it might result from actual variation in properties of the material.

In any case, the testing of the huge sheets of steel used in the automobile body industry to-day is made extremely difficult as a result of the variation in properties to be found at different points in the same sheet. The degree of rimming in the ingots of steel for cold pressing varies considerably as well as the degree of difference in composition between the rim and core of the ingots. As a result of this, the steel at the ends of sheets frequently has entirely different physical properties from the centre portion of the sheet. A steel showing pronounced " core " will also usually possess distinctly inferior ductility in the longitudinal direction to that in the transverse direction. The location of the test piece in the sheet may thus have a marked effect on the test results obtained. Then, again, this lack of homogeneity in the material may have no detrimental effect in the case of certain pressings, whereas in other instances it may be the main cause of failure.

The sheet manufacturers sometimes complain of the inability of their company to provide them with a definite specification to which to work. He thought that they would be much nearer to satisfying their desire when they can supply homogeneous material, and until that time they can only make use of test results as a guide. On this subject of quality of steel, Dr. Desch makes two statements of considerable significance: " It may well be that improvements in steel making practice will be the principal means of overcoming the present difficulties in the pressing of soft steel," and " There is little doubt that progress . . . will come from a thorough investigation of the metallurgical condition of the material at each of its various stages, *beginning with an improvement in ingot structure*."

In Dr. Desch's paper the author speaks of stretcher strains being *removed* by cold rolling—presumably he means *prevented*. He also makes the statement that " Pure metals are softer than alloys and are more liable to give wrinkles," whereas I find in practice that the softer the sheet the *less* trouble experienced with wrinkles.

Mr. A. Allison: It seemed to him that the crux of this symposium is to be found in the remark contained in the paper by Dr. Gough and Dr. Hankins that it ought to be possible to specify in advance a desirable material. In other words, the object should be to provide acceptance tests, and that means delivery tests as well, to indicate that the materials will perform their function. In his opinion, pressings are almost as bad as castings, because they may be of almost any conceivable form. He did not think it is possible to specify an acceptance test for pressings generally, but it might be for a particular pressing.

Reference has been made to co-operation between supplier and consumer. That co-operation is not always as close as it might be. Pressings are so varied that the steel is also varied to meet the conditions. It is quite possible to specify a steel for a particular job, and in this connection he quoted the figures given by Dr. Gough and Dr. Hankins. They point out that the mild steel samples, FVN 1 and FVN 2, were both unsatisfactory for deep pressings; sample FWN 1 was unsatisfactory for deep pressing, and FWN 2 was satisfactory. He would have expected that FWN 1 would have been satisfactory for the purpose for which FVN 1 and 2 were intended. In other words, that a 25-ton steel was required rather than a 21-ton steel. The tensile strength was not high enough.

A test similar to the Jovignot test appears to have been described in the *Journal* of the West of Scotland Iron and Steel Institute in 1926, according to the bibliography in the paper. It seems that this test is really carrying the Erichsen test to a further degree of refinement, but it is generally agreed by the speakers in the discussion that this one test cannot be considered alone.

There is one particularly difficult kind of pressing in which a central hole is punched and then the edges of the hole are bent up to form a kind of flange or tube. It seems that the Guillery and K.W.I. tests, in which a punched hole is expanded, are attempts to get over that difficulty. It is stated distinctly in the description of the test that the edges of the punched hole should be carefully smoothed over, but in a press shop there is no attempt to do this, so that there is a clear difference between the test and the press shop operations.

He would like to make a few points of criticism with regard to Dr. Desch's paper. He suggests that stretcher strains are bands of unequal work-hardening. It appeared to him that these objectionable stretcher strains are not bands of unequal work-hardening, but that some bands of crystals have slipped and have allowed blocks of crystals to slip, entirely unhardened and unstrained.

With regard to the excessive grain growth, Dr. Desch suggests that the range of critical deformation is from 5 to 30 per cent., but he thought the range is much narrower than he indicates, and that the range of from 9 to 20 per cent. is much nearer. Oxidation may also be a factor.

Coming to the contribution by Dr. Sachs, he felt that his work and that of his colleagues, in the numerous papers to which he refers, is really valuable. Pressings are very complicated things; they are of any conceivable form. Dr. Sachs' paper confines itself to the most simple pressing one can possibly have, the plain cylindrical shell, and it seems that that gives them a most excellent start for further research into pressings of much more complicated shape.

In the section of his paper dealing with tool form and drawing capacity, he refers to the curvature of the punch, and says that the curvature must not exceed a definite upper limit. From the figure in the section dealing with blank-holder and drawing capacity, it would seem that the failure occurred with a very small curvature. It may be that in the course of translation a negative has been displaced. He thought Dr. Sachs' work on the curvature of the punch and the die, coupled with the pressure on the blank-holder, is particularly valuable.

On the last page of the paper Dr. Sachs states that the fully annealed condition is not in every instance the most favourable. He agreed, and that is what he had in mind when he suggested that Dr. Gough's 25-ton steel would probably satisfy the demands where a 21-ton steel had failed. Dr. Sachs' remark confirms

the point. Dr. Sachs also insists upon the importance of lubrication and the condition of the surfaces, and he thought they all agreed with him most heartily thereon.

Finally, he refers to the production of ears or excrescences. It seemed to him that all circular pressings have ears, but it is a question of degree as to whether they are objectionable or not.

The following figures illustrate, among other things, the point that it is impossible to put forward acceptance tests for material to satisfy every pressing.

FIG. 5.

Fig. 5. Each of the little bulges, about $\frac{1}{4}$in. dia., is punched out, and makes a small article. The steel is a most difficult type to produce, and we would be glad of a specification which would meet the requirements.

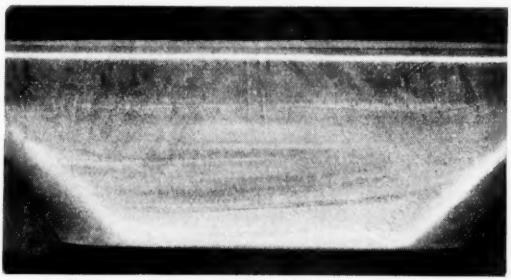

FIG. 6.

Fig. 6 is a side view of a pressing about 16in. long, and illustrates the point that the steel which gives a very good Erichsen or tensile test does not always give a satisfactory pressing. He thought this is about the limit of size which a good deep-drawing steel would make.

Fig. 7. This pressing is about 36in. long and 22in. across. He suggested that is definitely a case where a steel having a high Erichsen value and a low tensile would not be used. Reverting to Dr. Sachs' remarks about the pressures on the blank-holder, it is quite evident that there must be a ratio between the depth of the pressing, the span of the pressing, and also the area on which the pressure of the blank-holder is applied. This particular form of pressing is definitely one which calls for a high tensile steel, and he wanted to call attention to the ranges of these pressings, from possibly $\frac{3}{8}$in. dia. to 36in. dia. and the almost impossible task of providing a specification which will satisfy these requirements.

Fig. 8. The remark was made by Dr. Gough about a steel which gave excellent tests, but failed, and he hinted rather broadly that if the steel were used for a deep pressing such as this, it is not the fault of the steel if it develops splits. This pressing gave excellent Erichsen tests.

Fig. 9 exhibits a form of stretcher strain in which the strains are largely parallel, and across the direction of rolling.

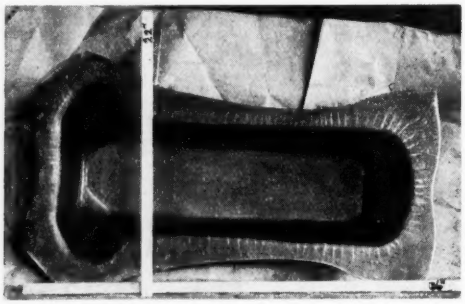

FIG. 7.

Fig. 10 illustrates a large pressing, and he had included it to show how the lines of force affect the flange.

Mr. J. R. HANDFORTH: Dr. Gough is apparently interested in the development of a testing machine which will select material suitable for press-work. The fluid-pressure machine which he favours is neat and ingenious. Without

FIG. 8.

having had time to examine it in great detail, he would not like to offer any criticism of this machine, but from the study of Fig. 2 and Fig. 5 he felt doubtful whether tests of this type can give the information which is desired with regard to the behaviour of materials in service. It would appear that in the Jovignot and N.P.L. cupping tests the material is held too rigidly between the pressure block and the die, so that when the pressure is exerted the material under test merely extends as in a tensile test, because it is unable to flow from the edges of the test piece. The illustration, Fig. 2 in the paper by Dr. Sachs, clearly shows the virtue of this provision for flow from the sides of the test piece.

Various speakers have suggested the difficulty of correlating tests on materials with the behaviour of those materials in press tools, and it would appear to be well worth consideration to make the press tool the testing machine, for experience has shown that in this manner material can be selected which will give complete satisfaction in the press shop. It has already been stated that the greatest difficulties in press work arise from " stretcher strain " effects. The

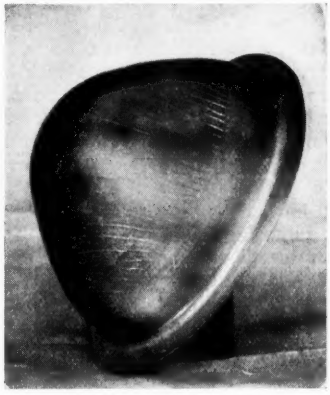

FIG. 9.

relation between " stretcher strain " effects and measurements taken in tensile tests was very clearly demonstrated by Dr. L. B. Hunt in his recent lecture at Newport.* With a knowledge of the general characteristics of these effects a press tool test has been developed in the works with which he was connected which is comparable to the A.E.G. test, and with which they can regularly select material suitable for the press tool work. A sheet of material, 7in. square, is

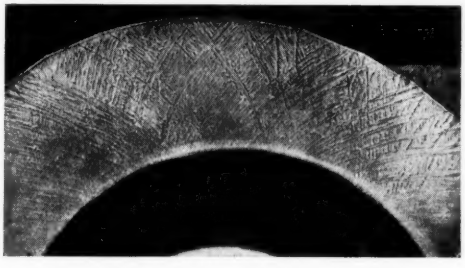

FIG. 10.

laid on a circular die having a 2½in. dia. hole with a radiused edge. A flat-ended punch 2in. dia. with a radiused edge, located axially with regard to the hole, is pressed down on the sheet and the material is judged according to the depth of impression which can be obtained without fracture. Three test pieces are usually used; the first is pressed to a depth of ½in., and the second to a depth of ⅝in. According to the appearance of the second test piece the third test

* Sheet Metal Industries, 1935, Vol. 9, pp. 101 and 154.

piece is pressed either $\frac{9}{16}$in. or $\frac{11}{16}$in. Any material which will allow the depth of the impression to be $\frac{9}{16}$in. or over is capable of being manufactured into very complicated pressings. The size of the test piece is important, for it bears a definite relation with the Lüders lines and " stretcher strain " effects which are produced by these tools. The test piece is held between the pressure block and the die sufficiently rigidly to prevent it from wrinkling, but sufficiently loosely to allow the material to draw. If the test piece is only 6in. square, at the end of the pressing operation it is no longer square, but shows marked indentations on each of the four sides. The minimum size test piece at which no indentations are produced in the sides of the test piece seems to be 7in. square, and there is no advantage in using larger test pieces. This test has the merits that it is simple and cheap, and experience has shown it to be reliable.

There are two other points of practical interest which may be of value to users of press tools. In material prone to " stretcher strain " effects they had sometimes found that this material would press comfortably when oil quenched from 900°C., when if air cooled from 900°C. it was sometimes still difficult. This is useful where local hardening by stretcher rollers or levelling machines is not practicable. Another important detail which has been mentioned by several speakers is the use of suitable lubricants. They had occasionally found that an addition of 2 per cent. of lead oleate to the lubricant would give success where other lubricants failed.

Professor W. R. D. Jones: Although he could not as yet see the Jovignot cupping test showing a greater utility than some of the older cupping tests, the mechanics of the test are good and the results so far warrant industry giving close co-operation to the National Physical Laboratory, so that sheets which are definitely good or bad shall be tested. The Erichsen test, which is well known in South Wales, is admittedly a comparatively crude test owing to the factor of friction. The test can give so many results on the same material. It is general practice not to use any lubricant in order that more comparative values may be obtained. The test, however, is useful as a quality test provided its limitations are acknowledged. There is a test which has found favour, and that is the alternating bending test, which is used in conjunction with the Erichsen test in some works. Although many alternating bending machines have in the past been devised for the purpose of testing strips cut from sheet metal, none appears to have met with universal approval. A machine called the Jenkins bend tester has been developed. Mr. J. C. Godsell has carried out a large amount of experimental work with this machine, and has commented very favourably upon it. It is a simple machine, capable of wide use and on giving discriminating results. It has one advantage in that bend tests can be carried out with safety upon strips cut from Erichsen test pieces after applying the latter test, provided, of course, that the line of bend must not coincide with the corrugated portion of the Erichsen test piece.

He hoped that further cupping tests will be carried out to show one way or another their value as indicating differences of behaviour of sheet in service pressing operations, and he hoped that the authors would see their way clear to carry out alternating bend correlation tests with the Jenkins machine. Since certain private specifications include the chemical composition, he felt that the analyses of the sheets tested would be a valuable addition.

Figs. 9-12 are most illuminating and give added support to the tensile test. Owing to the general use of this test, would the authors consider that the development of this test for sheet metal and the more widespread use of ductility diagrams give discriminating information as to the behaviour of sheet metal in the actual pressing operation?

Dr. Desch has given a great deal of valuable information as to the necessary properties of the sheet from a metallurgical point of view, and he would like to emphasise the fact that chemical analysis alone is no criterion of the suitability

of a sheet for stamping purposes. A low phosphorus content of 0.04 per cent. is the usual specification maximum for extra deep stamping material, but personally he did not think that 0.06 per cent. phosphorus would do much harm in steel for very deep stamping if one could guarantee that no sheet and no portion of any one sheet contained much more. Unfortunately, owing to the strong tendency of phosphorus to segregate, it is probable that if 0.06 per cent. of phosphorus were specified some portion of the sheet would contain more than 0.10 per cent. phosphorus. It is not surprising that the provision of suitable steel of required drawing properties is often left to the supplier either of the sheet or of the steel, and in many cases (in South Wales) there is an arrangement between the maker, roller, and user. It is, however, desirable that specifications should be drawn up. These papers and the discussion should prove valuable to the Iron and Steel Industry Committee of the British Standards Institute in the preparation of a specification relative to steel sheets for general engineering purposes.

There is a considerable difference of opinion in works as to the relative advantage of normalising and of box annealing. A normalised sheet can be considered to have a smaller and more even grain size and has less directional properties. It is consequently rather stiffer than a similar sheet box annealed even under best conditions, but if the stampers worked more slowly, the sheet would stand deeper stamping, while normalised sheets may be more even and the output more regular. For a very high class of deep-drawing material normalising is probably necessary to give a grain size in the region 1,000-1,500 grains per sq. mm.

Although the carbon content of sheets for deep drawing is low, a great deal depends on the mode of occurrence of the carbide. If the cementite is not large in amount and is well balled up it does not appear to affect seriously the toughness of the sheet, but if it forms a more or less complete envelope around the ferrite grains it does have a most serious embrittling effect. In either case the sheet would be improved by heating to about 900°C. and cooling moderately quickly, *i.e.*, a normalising operation.

A stamping can be made from a sheet which has a definite preferred orientation, and also from a sheet which has no directional properties, but the stamping made from the former is more liable to have internal stresses left in it, and one can imagine a type of failure similar in character to season cracking in brass, especially if there be a corroding influence at work. This type of "hidden defect" is not made apparent by ordinary mechanical testing or by microscopical examination. What is wanted is some non-destructive test which can be applied to each individual sheet. It would be interesting to have the authors' opinion as to the possibility of setting into acoustical vibration the sheet suitably supported and obtaining series of Chaldni figures which could be correlated with other tests, or with the behaviour of the sheet in service, and also whether some X-ray test could be adapted so that each sheet itself could be tested before the drawing operation.

Mr. E. R. Mort: To his mind the Jovignot test provides more complete information as to the characteristics of sheet or strip than any other cup test, and information that is comparable to that obtained by the tensile test. The tensile test is generally accepted as the most informative, but it does have the disability that considerable time is taken up in the preparation of test-pieces and this militates against its use as a control test in sheet works. In this connection it would be useful to know the time required to carry out a test on the Jovignot machine.

The importance of uniform grain size has been emphasised, while the difficulty of obtaining this by ordinary box annealing has also been mentioned. It is the usual practice to test sheets from the top, centre, and bottom of an annealing charge, and where the production is several hundred tons a day, the rapidity with which tests can be carried out becomes a factor. For this annealing control

testing, it is not usual, in sheet mills, to rely upon any one test, but to supplement the cupping test (Erichsen or Olsen) by a hardness test and micro-examination. The hardness test may be made on either the Rockwell or Vickers machines. Dr. Gough's opinion as to the value of combined results given by the three tests would be of interest.

Dr. Desch has referred to the different methods at present in use for the production of deep drawing sheets, namely, the regular sheet mill method, in which the sheet is hot-rolled to a thickness approximating to that specified, and the other method in which the metal is subjected to heavy cold-rolling—in *sheets* the cold reduction may be from 20 to 30 per cent., and in *strip* from 50 to 75 per cent. Considerable difference of opinion exists as to the relative advantages of the two methods, but from the theoretical point of view there is very little doubt that the rolling in strip form, involving heavy cold reductions, provides material which is more uniform in structure and thickness in the individual sheet, while the variation in the batch will be less than obtains in sheets produced by the old method. The structure obtained by low temperature box annealing in modern furnaces approximates to a normalised structure, while the surface finish, too, is of a high order. It may also be contended that the difficulties attending the production of wide material in sheet mills do not exist to the same extent in strip practice.

Another point that may be mentioned in connection with strip material is that the phosphorus content may be reduced to a very low figure, sometimes less than 0.01 per cent., and this would make for improved ductility.

It is well known, however, that cold-rolled strip has a decided tendency to age harden, and this has caused a great deal of trouble in cases where material was stored for considerable periods. The hardness may increase 7 to 10 points on the Rockwell scale, and the percentage of scrap will be excessively high unless the material is re-treated. It may well be that improvement in steel making practice will provide the solution of this difficulty.

A certain amount of doubt seems to exist, in this country, as to the suitability of cold-rolled strip sheet for deep drawing, but its use in press shops in America is increasing year by year, and it is difficult to account for this if the material really is unsuitable for the purpose. The operations involved in producing the fashionable streamlined American models can be no less severe than those connected with the manufacture of bodies for British cars, and he would welcome concrete evidence as to the superiority of sheet as against strip, for this purpose.

Normalising as at present practised is far from satisfactory, and finality as regards furnace design has yet to be reached. For certain special purposes cold rolled strip must still be normalised in order to give satisfactory results—although the greater proportion of strip is still box annealed only—and it seems possible that the operation might, in the future, be performed in an electric furnace and in a controlled atmosphere. It is understood that this development is at present receiving attention in this country. Rolling in strip form, with strict regulation of the process from the metallurgical point of view, and heat treatment in electric normalisers in a controlled atmosphere, would seem to meet the case put by Dr. Desch in the concluding paragraph of his paper.

Dr. G. A. Hankins: He would like to call attention to the fact that there have been in existence for a number of years various British Standard Specifications for metal sheet and strip material, both ferrous and non-ferrous, which are used for cold pressing and forming operations, and, of course, mechanical tests are specified. He believed that in every one there is a tensile test, and the values required are the ultimate tensile stress and the percentage elongation. In a number of these specifications bend tests are also specified; in some of them there are hardness tests, and in one case, possibly two, Erichsen tests. No very full details are given in those specifications as to the methods by which the tests should be carried out, and, accordingly, a certain amount of confusion was arising.

A Committee, with Dr. Gough as Chairman, was appointed to investigate the matter, and as a result two standard specifications for tests on metal sheet and strip material have been issued based on much experience. One for tensile tests, and another giving details of the methods which should be used in carrying out tensile, bend, and hardness tests on metal sheet and strip material.* Although it may sem fairly easy to carry out simple tensile or hardness tests on thin sheet material, actually it is one of the most difficult branches of material testing. Perhaps the most important point in regard to the specification is the standard form of tensile test piece.

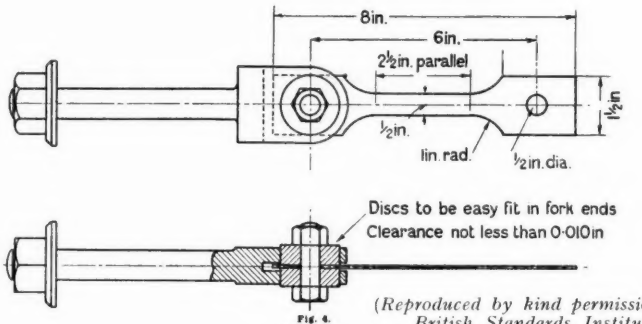

FIG. 4.

FIG. 11.

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Fig. 11 shows the standard form of tensile test piece recommended by the Committee. It is of 2in. gauge length and ½in. width. The important point is that in previous specifications test pieces of 8in. and 4in. gauge length, and others in which the gauge length has been equal to four times the square-root of the cross sectional area, have been used. In obtaining the ultimate tensile stress the form of the test piece may not be very important—although that is debatable in some cases. For sheet material the elongation results obtained depend on the form of the tensile test piece used, and that is why it is so advisable for everyone to use the same form of tensile test piece.

There is just one exception from that standard form; in the case of the deep drawing steels, it is known that the general elongation of the test piece, as distinct from the local elongation in the region of the fracture, is important. In this case it is better to use a long test piece, and it is suggested in the standard specification that for deep drawing steels a test piece of 8in. length and ¾in. width should be used.

In the view of the Committee, wedge grips are not the best for this special purpose, and the type shown is recommended, particularly for materials in which the ductility is not high. Details are also given in the specification of the methods which are to be used generally in tensile tests. Such debatable points as the definition of yield stress and proof stress are dealt with—a suitable form of extensometer is described, and comments are given on the accuracy of testing machines, etc.

Simple bend tests, very often useful and convenient workshop tests, give quite useful information about metal sheet and strip material; but a large number of methods are used as well as different sizes of test piece. The Committee, in making recommendations, has endeavoured to state the general principles on which bend tests should be carried out, and it has not specified any particular form of machine.

* British Standard Specification for Tests on Thin Metal Sheet and Strip, No. 485, 1934.

Hardness tests are also dealt with. The chief point in connection with hardness tests on sheet material is that there must be adequate thickness of material when tests are being made. At present the Rockwell test is not recommended in the specification.

Finally, a specification of this kind would not be complete without reference to cupping tests. They are mentioned in it, but no particular form is recommended for general use. An extract states:—

> " From the evidence which has been placed before it, the Committee, while appreciating the value of cupping tests, does not feel justified in recommending a test of this kind for specification purposes. There is no doubt that it does afford some indication of workability and ductility of thin metallic materials if the results are interpreted with discretion, but the test does not provide a reliable indication of the probable behaviour of the material under cold pressing and drawing operations."

This refers to cupping tests as they were some 18 months ago. There is another point of interest with regard to cupping tests. The specification states that:—

> " The surface appearance of the dome provides an indication of the original grain size of the material and the probable appearance of the surface after pressing. This particular and important aspect of drawing quality is definitely indicated by the test."

Dr. G. L. KELLEY (*communicated*): With reference to the Jovignot test, it is probable that a true dome form will appear only in plastic material. This follows because the amount of work done on material under test increases as the distance from the grips increases. With a semi-plastic material that portion which is near the grips may be worked to such a slight extent that it does not exceed the elastic limit. It is his recollection from the observation of domes formed in a similar manner, but approximately 12in. dia., that there is always a reverse curve near the grips. This test does not correspond with drawing operations in the automobile body industry, except in such formations as window and door openings, when the material is held firmly in the grips. The K.W.I. test corresponds more nearly to the window forming operations as employed at The Pressed Steel Co. than does the Jovignot test, and might be more valuable for that reason. To refer once more to the Jovignot test, it would seem to him that the material nearest the rings would tend to elongate in one direction only and that the top of the dome would be elongated in all directions. The effect of this, if true, would be to bring only a small amount of material into the actual test, and this appears likely from the location of the actual failure.

It would be better if the authors had shown a longer list of individual tests in order to show the consistency which may be expected in any particular type of test.

It is remarked that a low yield point is an advantage. This is probably because the compressive strength is low and the residual capacity for work hardening is greater. He was inclined to believe that the extent of the ability to work harden during the drawing operation, with the resultant increase in specific strength, is an essential quality in a material which is to be subjected to drawing operations. The effect of this is to transfer the load to successive sections adjacent to that which first yields, with the result that the elongation tends to become " general " rather than " local."

Concerning stretcher strains: this phenomenon is more or less related to the transition from the elastic to the plastic condition in the material, to the capacity for work hardening, and to the capacity for age hardening. The existence of the capacity to age harden is generally undesirable in stampings used for making motor car body parts, because probably nothing is added to the strength of the final part by this change which occurs in the metal. There are other instances,

however, where the capacity to age harden when cold worked is a very valuable one, and it would be a great disadvantage if it disappeared. He had in mind the age hardening which follows the taper rolling of discs and the same phenomenon which occurs after the cold forming of motor car wheel rims. If some measure of age hardening did not occur after these cold forming operations, it would be necessary to add very materially to the thickness of the stock, with a consequent great increase in weight. While he had only given two examples, a great many could be supplied.

Dr. MAURICE COOK (*communicated*) : Those conversant with the nature and technique of cold pressing operations and with the manufacture and properties of materials used for making cold pressings appreciate full well that from the results of any of the usual tests it cannot be foretold whether the material tested will press satisfactorily, since the success of the pressing operation is determined just as much by the conditions prevailing in the pressing operation, *i.e.*, die design, lubrication, clearance between punch and die relative to metal thickness, etc., as it is by the properties of the material being fabricated. It may well be asked what, then, is the value of the tests which are commonly carried out on strip and sheet metal in relation to presswork. Assuming that the material, be it ferrous or non-ferrous, is not inherently abnormal because of incorrect composition or because it contains impurities unusual in nature or amount, defects which can, of course, be readily detected, the usual tests such as tensile, cupping and hardness tests and grain size determinations, do not ultimately amount to more than check tests on the temper of the material and on the correctness or suitability of the fabricating processes, more especially perhaps the final annealing operation.

The results detailed by Dr. Gough and Dr. Hankins and the opinions of investigators referred to by Professor Sachs indicate, as one would expect, that of the tensile test and the various forms of cupping test which have been used, none is outstandingly discriminating, and it would not appear that there is much more to hope for from cupping tests of the fluid-pressure type. However, since the carrying out of tensile tests on very thin material is notoriously difficult, the fluid-pressure cupping test may prove to be in these circumstances a satisfactory alternative to the tensile test.

It is one thing to consider the most suitable form of check test for determining the temper or condition of presswork material, which usually resolves itself into a question of convenience more than anything else, and quite another matter to consider whether the relative pressability or workability of different materials can be established by reference to any of the several tests so far devised and used. The latter problem necessitates a comparison of the properties of a range of different materials, preferably each in a range of tempers, and an attempt at correlating them with actual pressing operations carried out under conditions as constant as possible. It seemed to him, apart from such factors as surface condition, which undoubtedly is of great importance, and grain size, which should not only be small but uniform, that of the several values which can be ascertained from the usual so-called physical tests, the value for uniform elongation is probably one of the most important. The significance of this property in connection with drawing operations has been commented upon in a paper* by E. C. Larke and the writer dealing with elongation values of copper and copper-rich alloys. As Professor Sachs has rightly pointed out, the fully annealed condition is not necessarily the most suitable one, and it would seem as if the suitability of a material for presswork or drawing, in so far as it can be determined by physical tests, is probably best indicated by a consideration of the values of uniform elongation and tensile strength together.

* M. Cook and E. C. Larke, J. Inst. Met., 1934, LV., 165.

Mr. H. H. Stanley (*communicated*) : Dr. Desch refers to stretcher strains on mild steel sheets, and states that " the severely strained bands are harder than the neighbouring regions of less strain by about 5 per cent," which suggests that both regions are strained, one to a greater degree than the other.

Tensile test strips—about 10in. by $\frac{3}{4}$in. to 1in. by 0.040in. (20 G.)—are very convenient specimens for the development and examination of stretcher-strains. Careful examination of the stretcher strains formed on such specimens by pulling in a tensile machine just past the yield point discloses the fact that the markings consist of *strained* and *unstrained* regions, alternating with one another. In the case of mild steel in the normalised condition, the difference in gauge between the two regions is about 3 per cent., *i.e.*, rather more than 0.001in., the strained region having decreased in thickness, the step from unstrained to strained material (of the order of 0.0005in.-0.001in.) giving the undesirable surface markings. Corresponding with the 3 per cent. decrease in thickness is an elongation in the direction of the stress of 3.5-5.0 per cent., and a reduction in width of about 1 per cent. (see Fig. 12).

The hardness difference between the strained and unstrained regions in this type of material is from 15 per cent. to 25 per cent.

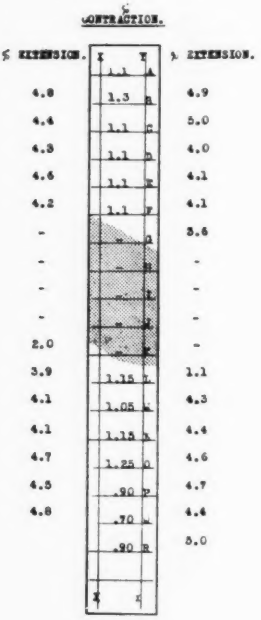

Fig. 12.

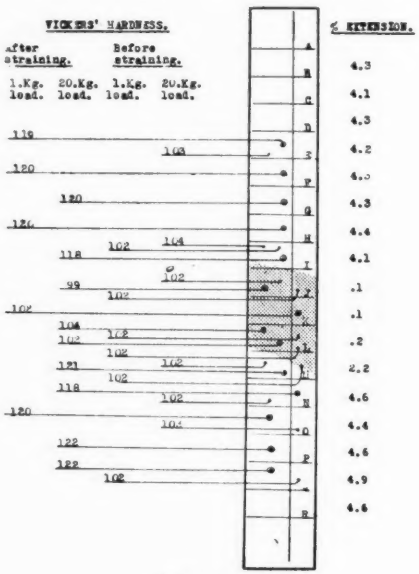

Fig. 13.

Vickers Hardness (20 Kg. Load).

	(*a*)	(*b*)	(*c*)
Unstrained	76 ...	102 ...	97.6
Strained	96 ...	122 ...	115
Difference	26.5 per cent. ...	20 per cent. ...	18 per cent.

The hardness difference in these cases probably represents a maximum. In material which has stretcher-strained after cold-rolling and ageing, the hardness difference is less than in the above cases, but is generally more than 5 per cent. (see Table I).

TABLE I.

MILD STEEL SHEET, 0.040 IN. THICK, NORMALISED AND COLD-ROLLED 0.5 PER CENT.

Vickers hardness before straining and ageing : 90 ± 2 (20 kg. load).

Aged at 150° C. for	Increase in hardness after ageing and pulling in tensile machine. Unstrained region (*i.e.*, aged only).	Strained region (*i.e.*, aged and strained)	Difference in hardness between strained and unstrained).	Extension in strained region, per cent.
3 min.	4.9	14.1	9.2	1.9
6 min.	7.2	22.7	15.5	4.0
12 min.	7.2	23.0	16.8	3.9
40 min.	7.1	27.3	20.2	4.8

When highly polished test strips are pulled in a tensile machine, straining starts at either end near the grips, and the steps from strained to unstrained material can be seen to travel towards one another, leaving behind them thinned-out and strain-hardened material. When these steps or strain-waves meet they damp out each other, although sometimes faint markings are left behind which may disappear later with greater straining.

If centre-punch marks are made on the strip before pulling, waves start from either side of each mark, travelling away from each other, being more or less damped out when they meet other waves travelling in the opposite direction from adjacent punch marks. It appears that any surface marking or strained area will give rise to stretcher-strains in the same way as centre-punch marks. The distribution of these strain centres, combined with the distribution of the stresses, may be responsible for the strain patterns sometimes seen on the surface of sheets after pressing.

Fig. 12 illustrates the non-uniform stretching which occurs on a test strip pulled just past the yield-point. The intercepts, which were made with the point of a fine needle, were measured up carefully by means of a vernier microscope (sensitive to 1/100 mm.), before and after pulling. The lengths A-B, B-C, etc., were approximatly 1 cm.

Fig. 13 shows the Vickers hardness before and after pulling in both strained and unstrained regions.

The values given in Figs. 12 and 13 are typical of those obtained in a large number of experiments on sheet steel in the normalised or annealed condition. Duplicate specimens in each case were pulled to fracture, an autographic stress-strain diagram being taken at the same time. The horizontal part of the curve—or the yield-point extension—agreed very closely with the average extension shown in Figs. 12 and 13.

Table I illustrates how the hardness difference may vary with the amount of ageing following cold-rolling.

It is well known that stretcher-strains appear on material which shows a sharp yield-point followed by an appreciable yield-point extension. A characteristic of such material is that, as soon as yielding starts at a point, the material there actually becomes weaker (as measured by the stress required to make yielding continue), with the result that yielding continues at that point for a time, instead of starting at other points. On the other hand, with a material which does not show a sharp yield-point, work-strengthening occurs as soon as yielding starts, *i.e.*, as soon as the slightest yielding has occurred at some point, a greater stress is required to make it go on yielding or extending there than to start it yielding at another point. The stress-strain diagram is characterised

by a downward slope immediately following the yield-point in the first case, and an upward slope in the second.

The drop in the yield-point on straining in tension apparently corresponds with the decrease in the yield-point, together with the disappearance of the yield-point extension, which follows small amounts of cold-rolling.

Extension by cold-rolling, per cent.	Yield point, tons per sq. in.				
	(*a*)	(*b*)	(*c*)	(*d*)	(*e*)
0	17.1	16.6	15.0	12.5	13.3
0.5	14.2	13.1	13.1	10.7	13.0
1.0	14.8	14.4	13.6	11.4	12.1
2.0	16.6	16.7	14.2	13.8	14.6

The drop in the yield-point is clearly brought out in *Fig. 14. The minimum yield-point corresponds with 0.5-1.0 per cent. cold-rolling. Greater amounts of cold-rolling result in a rise in the yield-point until, with 3-4 per cent. extension, it is the same as in the untreated condition.

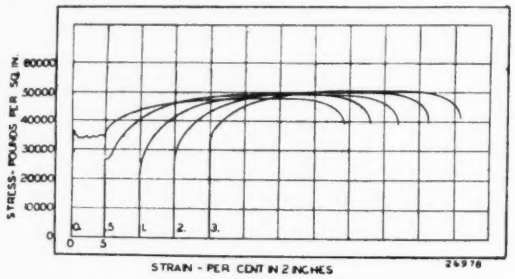

FIG. 14.

Stress-strain curves of normalised, box annealed mild steel sheets temper cold-rolled 0, 0.5, 1, 2 *and* 3 *per cent., and tested fresh.*

Although cold-rolling and straining in tension have not absolutely identical effects, they both show, for small values, the same tendency to bring the material into a condition when its resistance to permanent deformation is reduced.

If we regard mild steel as " sensibly isotropic," as suggested by Dr. Desch, and imagine the test specimen as being divided up into a series of small elements or slices, cut at right angles to the axis of stress, then, if yielding starts in one of these elements at a certain stress, resistance to further yielding will decrease as elongation and reduction in cross sectional area go on; deformation will continue there until, after about 3-4 per cent. extension, the yield-point will be slightly higher than that of the unstrained elements adjacent. Then they in turn will yield, work-strengthen, and pass on the effect to their unstrained neighbours. Thus, strain waves will pass away from their points of origin in opposite directions.

Although it is necessary to give mild steel 3-4 per cent. extension before it work-strengthens to its original value, very much less than this extension in cold-rolling will prevent stretcher-strains. For this purpose, it is sufficient to cold-roll 0.5-1.0 per cent.; this brings the material to the state when its yield-point is a minimum. Then any further deformation in tension gives immediate work-strengthening, a condition associated with a smooth stress-strain diagram and freedom from stretcher-strains.

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* See Griffis and Kenyon, " Ageing of Mild Steel Sheets," American Iron and Steel Institute, May, 1933.

Closely connected with stretcher-straining is the phenomenon described as "fluting," *i.e.*, the sudden "give" or "break" of soft annealed sheet steel when it starts to bend. It is obvious that the rate of work-strengthening must govern the radius of the bend. Material which work-strengthens immediately and rapidly will give a greater radius at the bend than material like annealed mild steel, which does not work-strengthen until it has received 3 per cent. extension. The radius of the bend under standard conditions should be closely related to the yield-point extension, and this radius might form a rapid means of measuring this value.

Mr. J. W. Berry (*communicated*): He felt that the results of the research on fluid-cupping tests were inconclusive, and did not get them very far, nor did he think any similar research is of any value, unless directly allied to actual practice. Cold pressing is a complex problem, and it is difficult to imagine any one test which will satisfy all needs.

He would like to know in how many directions Dr. Gough was disappointed in his applications for materials for test, as he personally, during a visit to N.P.L. in 1931, when fluid-cupping tests were discussed, offered to send in whatever material was required, but have so far had no application.

The paper by Dr. Desch is a very informative review of present-day materials, and offers one or two useful points of research, one of particular interest being the time period in connection with stretcher strain. Another is the critical work-hardening between heat treatment. This latter is, to his mind, of prime importance, both to press tool operators and to steel suppliers.

His experience is that users either expect too much of steel before heat-treatment, or they anneal at the wrong stage of operation. The question of bright normalising has now passed the experimental stage, and is merely being held up by economics. Successful bright normalising can be done by using an electric furnace with a controlled atmosphere obtained by using either cracked ammonia or butane. The present cost of the electrical supply, however, is against its general use. This cost factor may also preclude the general use of titanium aluminium steel.

The paper by Dr. Sachs is an excellent foundation for further research, and, in the writer's opinion, is one way to tackle the problem. One of the major causes of the present difficulties is that press tool operators are working very largely in the dark. Such being the case, they naturally take the line of least resistance. They try out more or less by experiment, and the tendency is to regulate their demands on the basis of 100 per cent. steel. In general engineering design the factor of safety is always introduced, but he suggested that this is not the case with press tool operators.

If they could have fundamental research on the safe reduction of various metals, say, for first and second operation plain cupping tests, and similar work on irregular shaped pressings, they would be moving towards at least a more intimate knowledge of their problems.

Dr. T. Swinden (*communicated*): The work reported by Dr. Gough and Dr. Hankins will be welcomed by all interested in strip and sheet steel, if only to confirm that the cupping test does not provide a complete answer as to the suitability of material for deep drawing, irrespective of the type of cupping test or metals used. It would appear that the fluid-pressure cupping test has certain advantages over other types, and is likely to be developed if suitably constructed for handy use. The authors show that if this test is used to construct a stress strain diagram, such a diagram is the best laboratory indication of the properties of the material as regards the suitability for deep drawing. It must be agreed, however, that the stress strain diagram obtained from a tensile test reveals the same information as shown in Fig. 9, and therefore, from this point of view, the matter simply resolves itself into the relative applicability of the two types

of test. The fluid-pressure cupping test might be considered preferable in that the stress is applied in all directions across the face of the sample.

As regards the steel samples, the evidence is somewhat disappointing in that it might have been forecast from the simple tensile test that sample FWN 1 would be unsatisfactory and that FWN 2 would be satisfactory. What is much more important, of course, is that samples FVN 1 and FVN 2, both of which gave apparently satisfactory tensile tests, behaved unsatisfactorily in service, and, moreover, that none of the cupping tests, as illustrated in Fig. 14, succeeded in differentiating between FVN 1, FVN 2, and FWN 2. It would seem strongly desirable that stress strain curves, similar to those shown in Fig. 9, should be published for steels FVN 1 and FVN 2.

It must be agreed, as Dr. Gough emphasised in introducing the paper, that the most important characteristic of steels for deep drawing is a high degree of plasticity. There are, however, cases where a certain minimum elastic limit appears to be desirable, and this will be referred to later in the discussion of the paper by Dr. Sachs.

There are one or two minor items in the paper by Dr. Desch to which reference might be made. In dealing with heat-treatment, he refers essentially to the treatment normally applied to sheets, namely, normalising or box annealing. The heat-treatment of strip steel is carried out under somewhat different conditions, and may be either continuous bright normalising or bright annealing in pots; the latter, again, may be either the commonly used method of packing in borings, or the more recent method of bright pot annealing without borings. The relative effect of these various methods of annealing on the production of ears in deep drawing is in itself a somewhat complicated problem.

In regard to grain growth on annealing following a critical amount of cold work, it is important to realise that this effect can be obtained if the steel is cold worked to a certain extent during hot-rolling. Some of the worst examples of disastrous grain growth in mild steel were produced by annealing cold finished, hot-rolled strip. Whilst this problem is not likely to arise in hot-rolled strip produced in modern mills, the subject has a direct bearing on sheet and plate rolling.

In reply to the verbal discussion, Dr. Sachs made a statement that fully annealed steel appeared to lose its plasticity earlier than similar steel oil-quenched from 900°C. It is in this direction that the question of elasticity, as distinct from plasticity, has some bearing on the behaviour during deep drawing. Although the analogy is by no means perfect, one might refer to the greater plasticity of patented wire compared with annealed wire during wire drawing. Although the patented wire has a comparatively low true elastic limit, its tensile strength is definitely higher than that of annealed wire, and its plastic range is far wider. While the question of work-hardening is of some importance, it is not primarily the explanation of the difference of behaviour of patented as compared with annealed wire, in that the work-hardening factor does not differ seriously, and, in fact, is slightly greater in the case of the annealed material. The difference is understood on examining the respective microstructure and visualising the mechanism of flow. In this discussion, the speed of deformation does not appear to have received the attention which, in my opinion, it merits. Plasticity depends largely on the rate at which the stresses are imposed. Many striking examples of this are readily available in both crystalline and non-crystalline materials. Some emphasis was laid on lubrication, and this clearly must be important. It raises the thought as to whether some simple coating, such as normally is applied to wire to facilitate drawing, might, with advantage, be applied to strip or sheet to facilitate deformation in dies.

Mr. H. J. POLLARD (*communicated*): One may say in general that, so far as steels are concerned, only the high tensile kinds are of real interest to the aircraft engineer. High stress development is a prime necessity for high

efficiency of structure, and where the attainment of high stresses is impossible then the higher tensile varieties of the light alloys should be used.

The art of cold deep pressing or drawing—as used in the motor car industry, for instance—finds only minor applications in the manufacture of steel or light-alloy parts for aircraft structures. There are, however, many bending operations in the manufacture of such parts, and he supposed that the bending which is done may be considered as a very simple form of deep drawing—say, drawing in two dimensions. Much ductility is required for these bending operations, and the way they get over the lack of ductility in high tensile steels is by working the sheet material to the desired shape while it is in the annealed state, then when all forming, drilling, etc., is finished, the part is raised to the required strength by hardening and tempering. Care is taken to see that the radii of the bending tools are not less than that quoted for the annealed state of the material in the specification. When cracking occurs—as it sometimes does—the steel sheets or strip are returned to the steel maker, so that one of the principal points raised in these very valuable papers concerns the steel sheet maker much more than the user.

There is one point in connection with bending sheet steel that may be of interest, and it is this: that most of the material which fails under the bending test is confined to a thickness of 16 S.W.G. Sheet or strip thicker or thinner than that seldom gives trouble. What struck him as remarkable is that the lack of ductility of 16 S.W.G. material is associated not only with the simple Ni, Cr steels, but is common with many other grades of steel sheet of 16 S.W.G. thickness. He suggested that that is a matter well worthy of the combined attention of metallurgists and steel sheet manufacturers.

From the papers and the discussion it would appear that such components as exhaust manifolds might profitably be manufactured by the deep-drawing process. The matter is certainly worthy of investigation. An exhaust manifold for an air-cooled engine is a large annular component of toroidal shape, some 4ft. 6in. dia., and some 2ft. 8in. internal dia., made from two parts dished and connected at the edges to form a chamber for the reception of the exhaust gases, the chamber being some 4in. deep. The cost of dies for deep drawing such a shape would be considerable, and he would welcome the authors' views on the relative costs of deep drawing these components and producing them by spinning for limited production.

Mr. E. COUPLAND (*communicated*): Those interested in the actual production of cold pressings cannot help but feel a keen sense of disappointment at the state of affairs as revealed by the three papers. Of the three papers, only that of Dr. Sachs holds out any real hope or suggestion for the future. If it is agreed that a number of materials, having widely differing properties as indicated by the tensile or other usual mechanical tests, may have approximately the same drawing qualities, then it is perfectly clear that press tool operators will not be interested in the further development of the fluid-pressure test, which merely offers an alternative to the present tensile test. The new test may offer the advantage of eliminating time in specimen preparation, but he had yet to be convinced that time will be saved overall, or that it is likely to be applicable to thick material. It is quite unlikely to replace the Erichsen test, which, for the main part, is used as an indication only and has the great merit of speed and simplicity.

The investigator who has not had actual press shop experience is apt to pay too much attention to the tensile properties of the material, because so many pressings ultimately fail in tension. While he agreed that a reasonable standard of performance in tension is necessary, he would state quite definitely that super excellent performance in tension will not offset: (*a*) inability of the material to flow in compression, (*b*) unduly rapid work hardening, (*c*) incorrect die design, (*d*) incorrect tool setting (particularly excessive blank-holder pressure).

In regard to item (*a*), he regarded Dr. Sachs' wedge test as being worthy of extended investigation; item (*b*) may be investigated at the same time by checking increase of hardness due to the wedge test immediately after the test has been made and again after suitable ageing; (*c*) can only be eliminated when it can be laid down definitely what can be reasonably expected from the material, and in this connection he has some suggestions to make for the classification of pressings. In regard to item (*d*) unless, for some special reason, it is required to stretch the material in one or more directions, then the blank-holder should not grip the material, but should be forced down on to the die (not on to the material), with sufficient force to ensure that corrugations are not allowed to commence, *i.e.*, the blank-holder must not be allowed to lift. The increased clearance beneath the blank-holder towards the centre of the die, as suggested by Dr. Sachs, is the obvious way of carrying the idea of no pressure on the blank to its logical conclusion.

Referring to his suggestion for the classification of pressings, he would appeal for a much wider use of the very old idea of marking off a blank prior to pressing, followed by a critical examination of the space distortion as shown by the markings after pressing. The best form of marking has yet to be determined, but obviously in the case of a circular pressing the marking off will consist of equally spaced radial lines and concentric circles. For other shaped pressings the marking will most probably be in the form of squares. The best size of the squares and the distance between the concentric circles again remain to be determined. It may be convenient to take some arbitrary size, say, $\frac{1}{2}$in. or 1in., or, again, it may be found better to take a multiple of the thickness. If the pressing includes much of the element of bending in addition to that of straightforward plastic flow, then it will be necessary to mark both sides of the blank.

Pressings could then be classified according to the maximum percentage in extension or compression of any line on the pressing, and some definite idea obtained of what is being expected of the material and what alterations are necessary to secure best die performance. The latter remark applies particularly to successive draw jobs. It will also be possible to compare the behaviour of competitive material, and to appreciate why one behaves better than another, and in this connection I would suggest that in the present state of our ignorance we are more likely to gain useful knowledge of the real differences between material which gives 2 per cent. scrap and that which gives 10 per cent. scrap by a closer attention to the good pressings than is usually given. Knowledge of how we succeed should surely help us to avoid failure.

Finally, in regard to Dr. Desch's paper, he felt a little disappointed that he regards the future of deep pressing steel as being wrapped up in rimming steel. He agreed that the making of rimming steel is an art, but there appears to be a very limited number of such artists in this country, and even they do not produce works of art as often as one would like. He was possibly crying alone in the wilderness if he suggested that the ultimate future of deep drawing steels lies with a really clean fully killed steel. He would hate to think that it is impossible to obtain a good surface on such a steel.

Mr. A. B. Winterbottom (*communicated*): The importance of surface conditions in pressing operations was generally recognised (*e.g.*, in steel tube drawing reductions in area of up to 80 per cent. or more could be obtained by the use of soft metal coatings), and, as has been emphasised by Dr. Desch and Professor Sachs, further progress would seem to depend on the evolution of techniques suitable for the investigation of these elusive surface qualities. The ordinary methods of mechanical testing, microscopy, measurement of power consumption, etc., in general, yield results in which surface effects were largely diluted and obscured by changes in the body of the material. Great strides are being made in the application of X-ray diffraction to the study of cold-worked

materials and internal stress distribution, whilst electron diffraction had also been used* to investigate " Small Scale Structure of Surfaces."† Perhaps very soon the application of such techniques will be so developed‡ that, in conjunction with established methods, it will be possible to examine and describe the constitution of surfaces with ease and precision.

Apart from investigations of materials and pressings on the lines suggested, the actual pressing operation itself may be susceptible to more detailed study than measurements of forces and energy consumption have hitherto afforded. Thus, for example, it may be possible to make instantaneous measurements of temperature and pressure distribution throughout a pressing by recourse to thermo-electric or piezo-electric methods with suitable amplifiers and oscillographs. Lubricant films could also be investigated by means of reflected polarised light§ as well as with X-rays and electrons.

Whilst Professor Sachs dismisses cupping tests as of no discriminative value with regard to drawing properties and advocates his own hole expanding test for that purpose, Drs. Gough and Hankins submit the results of their exploratory survey of the fluid-pressure cupping test as possibly worthy of consideration in this connection. In view of all that has been stated concerning the importance of surface condition and the probability that such a " kind " test is much less influenced by variations in surface than are ordinary drawing operations, as well as the test's inability to discriminate between materials of markedly different drawing quality, Professor Sachs' contention seems worthy of support. However, as has been stated, the fluid-pressure cupping test has, at any rate, the merit of a relatively simple, clearly defined and easily reproducible stressing action; and on that account it might have intrinsic value in sheet testing.

He was rather surprised that the authors found the cup to be of spherical form. Is this true or not for all materials for a reasonable range of thicknesses and diameters? He would have thought that if the cup could be treated as a thin shell then the equilibrium of an element would be defined in the usual way by :—

$$pr = 2ft,$$

where :—

p = the internal hydraulic pressure, constant over the whole surface in each stage of the cupping process,

t = the thickness, some function of position in the cup as well as stage of the cupping process,

f = the stress (membrane tension),

r = the radius of curvature of the element.

For this relation to be satisfied either the curvature must vary over the cup with the stress constant or the stress must vary if the curvature is constant, *i.e.*, cup spherical. During plastic deformation the stress is usually supposed to conform to the first condition approximately, though this cannot be true for material which work-hardens to any considerable extent. It would therefore be interesting to know whether any differences in shape could be detected between lead and, say, austenitic stainless steel, for example, to take extreme cases.

Reply to Discussion

Dr. H. J. Gough: In the limited time available at this meeting I cannot attempt to reply to all the questions which have been raised in the discussion. I would prefer to confine my present remarks merely to one aspect which indirectly concerns quite a number of the questions which have been asked.

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* *e.g.*, W. A. Wood, Phil. Mag., 1934/18/495-505.

† H. Möller and J. Barbers, Mitt. K.W.-Inst. Eisenforschung, 1934/16/21-31.

‡ G. P. Thomson, Phil. Mag., 1934/18, pp. 640-656.

§ L. Tronstad, Trans. Faraday Soc., 1933/29, p. 513.

When commencing any research problem in any branch of engineering or metallurgy, the first task is to form an estimate of the number of variables concerned, and then examination might show that some of these could be grouped, while others would be seen to be independent variables requiring separate study. It would obviously be absurd to carry out tests under conditions such that all the variables were operating to an *unknown* extent; then, having obtained an answer, to attempt to draw a deduction as to the effect of these independent variables. I draw attention to this point because a number of speakers have said that no test applied to the material can reproduce the complex conditions existing under a die, and therefore it is hopeless to look for such a test. Now, however complicated the form of the pressing, all will agree that the material is subjected to a definite system of stresses, and any complex system of stress can be reduced to simple components—a maximum of six. Further, if recent research results can be relied on, it is fairly clear that plastic deformation occurs under a single and definite condition of stress. This suggests the most likely avenue to be explored in the search for a test; if different materials can be associated with different flow curves, then I think there is a hope of being able to explain their relative behaviour under the die. On the other hand, if the subject is looked at from the point of view that in one type of work a certain shape of die is used and in another type another shape of die, and endeavour merely to correlate the suitability of a material for a particular die and a particular type of pressing, there is the risk of becoming loaded up with empirical relations which have no general application whatever. It should be recognised that the problem is one of *plasticity* and an endeavour should be made to find some test which will give an indication of the plastic properties of our materials; I feel assured that only in this direction lies a hope of success. Neither I nor my fellow-author come before you to-night and present to you this new cupping test with the comment that if you will employ this test on your steel it will tell you whether your designer in the drawing office, the die maker, the cold presser, and all the others involved, are working correctly. Those aspects must receive *separate* consideration. On the other hand, I feel that if the test we have suggested, or any other test, for that matter, does enable you to obtain a quantitative measure of the flow conditions of your materials, you will have got some practical informative data regarding the material.

With regard to the beautiful illustrations shown by Dr. Hatfield, I would say, in the first place, how very gratifying it is to see manufacturers coming forward and frankly exhibiting their failures. Everyone knows that failures occur, and, in my own opinion, more is often to be gained from a careful study of a failure than from the mere record of a successful job. But with regard to the particular failure shown by Dr. Hatfield, I wonder personally whether it is necessary to consider only the possible chemical effects involved. After all, immediately after a material is deformed plastically, there exist forces tending to produce a certain amount of elastic recovery. Under certain conditions, these elastic forces are released, but it is quite possible in certain types of cold pressing to deform the material into such a shape that severe restriction is imposed upon such recovery; the type of pressing shown by Dr. Hatfield in which a rim is formed in the material appears to be such a case where considerable internal stress may exist. It appears to me that, if a material is sufficiently heavily deformed and contains a sufficient degree of internal stress, fracture may result due to that cause; it becomes unnecessary to ascribe the result to the effect of chemical agents.

Mr. Arrowsmith raises a very interesting point. He remarks that both the Jovignot and the K.W.I. tests are apparently much more discriminating than the other forms of cupping test, and suggests that these two tests should be investigated further in connection with material whose plastic performance is known. Commenting that the shape of the K.W.I. test piece provides a very close parallel

to certain forms adopted in press operations employed in the automobile industry, he remarks quite rightly that the condition of the edge of the hole in the K.W.I. test might be expected to be extremely critical. I think this is a very important point. The conditions of the inside of the hole in the K.W.I. test must largely affect the result, and hence, in my opinion, this does constitute the basis for a general objection to the test. It appears to be adding a further complication by introducing an additional factor which may affect the result.

Dr. H. J. Gough and Dr. G. A. Hankins, in further reply, wrote: Since the main object of our paper, in addition to stimulating discussion on cold pressing and drawing in general, was to discuss mechanical tests on materials in particular, we intend in this written reply to deal in detail with only some of the comments made concerning mechanical tests.

In the first place, we would again stress that no one test can be expected to duplicate the complex conditions arising under the die. A true understanding of the mechanics of a pressing operation involves direct knowledge of the plastic distortion properties of a metal; these can partly be represented by a complete curve connecting load and deformation, other variables, such as rate of deformation, being kept under control. So that, although it is useless merely to select one point on a curve of that type and to suggest that it reveals the general characteristics of the material, such *complete* curves do give much more extensive knowledge than, say, a simple tensile test or an Erichsen test. We are definitely of the opinion that it would be advantageous to manufacturers to know the shapes of the load deformation curves of the materials they are using, and by combined experience and testing, relate the essential features of the curves to the practical knowledge gained in producing pressed articles. Only the complete tensile test or the complete oil pressure test gives a general curve relating load and deformation, and the discussion has strengthened our original opinion that by consideration of such curves real progress is likely to be made in relating the test characteristics of a given material with its behaviour in a particular cold pressing operation.

Mr. Richer raises the questions of speed of testing, "fool-proofness," strength, capacity, etc., of the N.P.L. fluid-pressure testing machine. Such questions, of course, would need to be given full consideration by any manufacturer before he installed a similar machine. Actually the time required for a complete oil pressure test with the apparatus is from 10 to 15 min., but it should be stressed that the present machine was not built with a view to carrying out tests on a works basis, and in this direction considerable improvements could undoubtedly be made. It would seem that for the present the most important point to consider is whether the machine and test so far developed warrants further investigation; does it show any indication of being more useful than existing tests? We are glad that Mr. Richer and other speakers consider that it has distinct possibilities, and if further work is carried out we shall be pleased to accept Mr. Richer's kind offer of co-operation.

We are not quite clear as to the meaning of Mr. Allison's comments on the mild steels FVN and FWN. It has been stated as a fact that the 25-ton steel (FWN 1) has proved unsatisfactory in service; this rather agrees with our own general experience that a high tensile steel having reduced ductility, associated with curves of the form shown in Figs. 8 and 9, was not generally so good in cold pressing applications as a lower tensile steel with greater ductility, such as FWN 2 (see also Figs. 8 and 9 for curves of material FWN 2). To be frank, we suspect that steels FVN 1 and FVN 2 are good steels; and suggest that the manufacturer who complains of their behaviour should look to some factor other than the quality of the steel to explain his trouble.

Professor Jones mentions the possible use of non-destructive tests. Such tests are attractive, but although the form of vibration test he suggests might give useful information on the *elastic* properties of sheet metal, presumably it

could not give much information regarding the *plastic* properties which are the important factors to be considered in the present application. The normal X-ray examination gives no information on the intrinsic properties of a metal, but is useful, of course, in detecting flaws, etc. In due time X-ray methods of examination may be developed as a practical inspection test for sheet metals, particularly in relation to cold working effects and surface conditions, but it is difficult to see their potential advantages in relation to the special problem under present discussion.

Mr. Mort asks for an opinion on the merits of control testing, using a combination of Erichsen or Olsen test, hardness test and micro-examination. As far as our experience goes, we find that for general control purposes good consistency of results is somewhat difficult to attain with the Erichsen test, since the values obtained depend to some extent on the operator of the machine and also on the variations existing between different machines. Thus two apparently similar Erichsen machines are not always in good agreement when operating on the same material. For works control we consider that the tensile test for yield stress, ultimate stress and elongation is probably better than the combination of Erichsen and hardness test, but the Erichsen test often gives information on grain size that is not obtained in the tensile test. For sheet metal the British Standard diamond pyramid test is to be preferred to the Rockwell test.

We agree with Dr. Kelley that the truly spherical form would not be obtained near the edges of the die in the oil pressure test; obviously, there must be a reverse in curvature of the sheet at or near the edge of the die, but the area involved appears to be small. The general question of similarity as discussed in the earlier part of our paper suggests that the actual amount of material which is effective in the test is a substantial part of the whole, although we agree that further experiment on this point is desirable.

Mr. Stanley's communication gives very useful information on yield point slip and its association with stretcher strains.

We greatly regret that Mr. Berry's offer to supply material has not been taken advantage of, and will certainly get in touch with him if further work is carried out. We entirely agree that further work on the cupping test should be carried out in close relation with actual practice. The desirability of this was stressed in the paper. We are in general agreement with Dr. Swinden in regard to his remarks on steels FVN and FWN. Complete curves are available for materials FVN 1 and FVN 2; they are very similar to those given in the paper for FWN 2, and we are of the opinion that the unsatisfactory behaviour of steels FVN 1 and FVN 2 is not primarily due to the quality of the material.

Replying to Mr. Winterbottom, we have not made exact measurements of the shape of the cup in all the oil pressure tests, but the measurements which had been taken lead us to think that for a very plastic material the cup immediately before fracture is a very close approximation to a portion of a spherical dome; this would probably apply to lead. It is also reasonably correct in the case of annealed stainless steel, which is a fairly plastic material, although, of course, very high pressures are required to deform it. With a material like the aircraft steel which has been used, in which the amount of plastic deformation is small, the deviation from the spherical form might be considerable.

It is clear that the oil pressure cupping test as put forward in our paper does not appeal to all those who have contributed to the discussion; we are glad that certain improvements have been suggested and questions raised, but after carefully reconsidering the whole matter, we still hold the view that the complete stress deformation curve obtained from an oil pressure test or from a tensile test offers a promising line of development. It is clear that the chief hope of progress is in close collaboration between actual works operations and laboratory investigations, and we shall always be eager to co-operate to the utmost of our ability.

Dr. C. H. Desch, also replying to the discussion, said: The discussion has turned mostly on the question of finding suitable tests to determine the deep drawing qualities of metals; the metallurgical aspects have not been so fully discussed. There is general agreement that improvement comes from the metallurgical treatment right from the beginning, so that I will not deal with that point further.

The point made by Mr. Allison concerning the critical range of deformation is quite correct. The range he gave, from 9 to 20 per cent., covers by far the greater number of cases, and that range is usually given. But on going through a large number of records I found cases in which critical grain growth had occurred after deformations ranging altogether from 5 to 30 per cent., and I put in that range to represent the outside limits. After all, in the process of cold working followed by annealing, there is no difficulty whatever in keeping outside those limits, so it is safe to give the wider range.

With regard to stretcher strains, I agree with Mr. Allison that there is a slipping of certain blocks over one another; but I do not think that any of those regions are entirely free from strain hardening. On using the Vickers diamond over a specimen showing stretcher strains, and making a large number of measurements, a large number of lines are found, but the strongly marked lines show a very appreciable increase of hardness—6 or 8 per cent. The form of the stretcher strains is very interesting, and Mr. Allison's excellent photographs brought out a point which should be noted carefully. In most of the cases the direction of the strains is the same as that of Lüders lines, which were obtained on specimens covered with scale, and the patterns worked out by Hartmann in a book forty years old, which shows every one of those patterns perfectly. On the other hand, sometimes the lines do not follow definite strain directions, but take flamboyant forms; they are very wavy and bear no special relation to the direction of the stress. One very striking example was shown in which the bands crossed one another at various angles. That condition would need a rather thorough investigation of the metal; it is quite a common case, but it depends to some extent on the crystalline structure of the metal, whereas those bands which take the form of Lüders lines are quite independent of the crystalline structure, and are obtained just as well in gelatin as in steel.

The point raised by Mr. Arrowsmith has now been corrected. The sentence was intended to mean that the liability to stretcher strains could be removed by cold working, and not the strains themselves.

The information communicated by Mr. Stanley is very valuable; it is just such a quantitative investigation of the strained material which was wanted.

An interesting point is also raised by Dr. Swinden in his statement that very serious grain growth in mild steel has been produced by annealing strips which had been hot-rolled, but had been finished at so low a temperature that critical strain was present. This particular defect should not be difficult to avoid. I feel that Mr. Coupland's suggestion that clean fully-killed steel should be used is, at present, a counsel of perfection. Scientific metallurgists would like to see all steels fully killed, and made in the most perfect state possible, but economic considerations at present compel the manufacture of large quantities of rimming and partly-killed steel. It may be hoped that in time it may be found possible to combine the somewhat contradictory requirements of complete soundness, perfect surface, and cheap production. In the meantime, it is well that the practice of making rimming or partly-killed steels should be improved so as to obtain uniform ingots. The defects to which Mr. Arrowsmith refers become only too obvious when large sheets are rolled, and the thesis maintained in the opening paper that improvement in the production of such sheets must begin with the ingot and be continued throughout the whole of the metallurgical processes has been generally supported by the speakers in the discussion.

Professor G. Sachs, also replying to the discussion, said: I have to answer only a few questions, chiefly those raised by Mr. Allison. The radius of curvature of the die or punch must be as large as possible, but if it is more than twenty times the thickness of the sheet, then the sheet wrinkles. As wrinkling is not usually permissible, it is not possible to have a radius of curvature greater than twenty times the thickness of the sheet; but it may be that in some cases some wrinkling is permissible.

With regard to ear formation, from Figs. 1 and 7 it will be seen that the brass used for the experiments had no ears. It is only during the last few years that many firms in Germany have found the conditions in which to produce brass and copper practically free from ears. I do not know what the conditions are for iron and steel, but I think there is some iron sheet which is free from this defect.

In regard to testing sheets, there are two quite different points to be considered. To make a single drawing as deep as possible, the first consideration is to have a material possessing a very high ductility. Materials which have high ductility, such as copper, brass, aluminium, and some kinds of steel, have a drawing capacity or a drawing quality nearly the same. Another important consideration is to have very uniform material, and a material with a good surface. The conditions of drawing are also important—the curvature of the dies, the lubrication, the blank-holder, the pressure, and so on. On the other hand, the tensile strength, or the elongation or cupping values of materials are very different, although they may have almost the same drawing capacity. The testing of ductility is a problem not yet solved. I have mentioned in my paper some experiments that are being made in Germany with the wedge test, in which we found a very curious effect. If there are two samples of the same steel, differing in their tempering—one annealed at 700°C. and the other normalised at 900°C.—the steel annealed at 700°C. loses its ductility by plastic deformation, as shown by the Erichsen test, much more quickly than the normalised steel. I do not think that the strain hardening is very different, but the loss of ductility is quite appreciable.

REVIEWS

Aricraft and Flying

By F. V. Monk and H. T. Winter. The Gresham Publishing Co., Ltd. Price 7/-.

This book contains a popular account of the aeroplane and engine, with a description of many of the technical matters concerned. It starts with a short account of ancient history, deals in some detail with aero engines and their fuels, discusses aeroplane matters, and finishes with chapters on gliding, notable flights, etc.

The authors have been successful in putting technical facts into language which the non-technical reader should be able to understand easily, and the book can be recommended to those who wish to know something about technicalities without reading text-books. To those who already understand something about aviation the book will be without interest, but there must be many general readers who would welcome a book of this type.

The Hardness of Metals and its Measurement

By Hugh O'Neill, D.Sc., M.Met. Chapman and Hall. 25/- net.

This is an important book on an important subject. Dr. O'Neill has included in it a complete review of hardness and the methods of testing it and has added a scientific investigation of static indentation tests and of other methods of testing. Much of this matter is of great importance as the limitations of such tests as the Brinell are not too well known.

Although everyone knows what the term hardness means, it is an extremely difficult term to define scientifically. It may mean resistance to abrasion and the test may consist of a scratch with a diamond or an attempt to cut the sample with a file. Practically it means usually resistance to an indentation test such as the commonly used Brinell, or degree of the rebound of a falling indenter, but, as the author points out, indiarubber by this latter test appears as a very hard material, whereas everyone knows it is soft. Actually it seems somewhat inconsistent to test for a quality which may mean resistance to indentation by producing an indentation of some size by the application of a considerable load through the medium of a steel ball. Logically the maximum load which would just not produce permanent indentation would seem superior, but there would probably be considerable difficulties in producing a satisfactory commercial testing machine on this principle.

The Brinell type of test is established now as the most common method of testing hardness, and whatever the scientific objections to its use, and to the method of calculating the results, there is no doubt that it is of immense importance to the steel industry as a practical method of testing hardness, and also of assuring the manufacturer or user of the steel that a sample is of uniform quality throughout, or of proving the opposite. It is one of the few tests which can often be applied to the actual piece of metal to be used.

This book is an important addition to technical literature, for nowhere else, so far as I know, can all information with regard to hardness testing, including data on such matters as heat treatment of metals for hardening, strain hardening, etc., be obtained within the covers of one volume. There is also an extensive and valuable bibliography.

Standard Methods for Testing Petroleum and its Products

Published by the Institution of Petroleum Technologists. Price 7/6.

The testing of products is a subject that increases in importance from year to year. Such tests have a tendency to become more complicated as attempts are made to measure the suitability of some substance for some particular commercial purpose by laboratory methods.

There is no field in which laboratory testing is more important than in that of petroleum products. Their range is extraordinarily wide, ranging from waxes to materials for road making and from lubricating oils to fuels. It is of special importance to aeronautics that petrols and oils shall be of standard and known quality and that each batch shall differ as little as possible from the others.

In many cases the tests are difficult to carry out, hence requiring the services of a skilled chemist. But in order that tests carried out in different laboratories shall be strictly comparable, it is necessary to lay down the methods and procedure with meticulous care.

This book has been produced for this purpose. All tests that are likely to be wanted are described in detail and standard apparatus is specific where appropriate. A particular feature of the book is the inclusion of a number of tests described as tentative. Among these are some of particular interest to aeronautical engineers, such as those relating to knock rating, and the information given with regard to these is as detailed as in the case of the others. In all such cases, the specifying of standard methods must be of great importance to accuracy.

The 592nd Lecture to be read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

An Ordinary Meeting of the Society was held in the Lecture Theatre of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2, on Friday, March 15th, 1935, when Senor Juan de la Cierva, F.R.Ae.S., presented a paper on "New Developments of the Autogiro." The paper was illustrated by cinematograph films depicting the take-off and landing of the latest type of autogiro.

The President of the Society (Lieut.-Colonel J. T. C. Moore-Brabazon) was in the chair, and the distinguished visitors at the meeting included His Excellency the Spanish Ambassador.

The PRESIDENT: It was indeed a pleasant duty to present Senor Cierva—it was not necessary to introduce him, for he was a very old friend. He had been awarded in the past the Society's Silver Medal, he held also the Wakefield Gold Medal and was a Fellow of the Society. No one could have anything but the greatest admiration for this man, because, single-handed, he had invented and introduced a new technique of flying. Although at one time the autogiro was laughed at as almost a toy, very great interest had been generated by the progress which Senor Cierva had made.

Nature, with all its wonders, had never introduced a wheel, and the inventor of the wheel certainly should have made a fortune. In Senor Cierva's machine we had, instead of flapping flight, sustentation by a rotary giro. The meeting would hear from Senor Cierva himself of the very latest developments he had achieved. It was delightful to know also that he had mastered what to him, apparently, had been more difficult than technics, *i.e.*, the English language, and the meeting would have the pleasure of hearing him read his paper in English.

NEW DEVELOPMENTS OF THE AUTOGIRO

BY

SENOR JUAN DE LA CIERVA, F.R.Ae.S.

It is my privilege to present to the Royal Aeronautical Society a brief summary of the work done and the results achieved in developing the autogiro in the last few years. Many fundamental improvements have been the product of that work, but of still greater importance is the considerable progress in the knowledge of the aerodynamics, dynamics and engineering requirements of the new aircraft. The improvements in the formula have been made possible or practical only because of the painfully acquired technique, which, as is the case in all new arts, is a compound of theoretical developments and empiricism.

One of the characteristics of the development has been the great number of difficult secondary problems. The very large number of parameters and the heterogeneity of the requirements, some aerodynamical, some dynamical and some structural, make correct compromising—which is the secret of all successful engineering—an exceedingly delicate task.

In many instances, sacrifices in one direction have had to be made in order to improve some other point, until increased knowledge has permitted to redress the balance again. Simultaneous progress all along the line is only possible when a final formula is established, and the autogiro is only now arriving at that stage. Until then it will necessarily lack that refinement of design which can only be attained by repeated steps in the same direction.

Let these considerations be my answer to those critics of the autogiro who ask, for instance, why, after such a relatively long development, we have failed to substantiate our early and repeated claims about the autogiro being capable of competing with the aeroplane in speed.

We are convinced of the potential truth of our claims and, if we had left aside the fundamental development, we feel we might have proved them by now. However, and as we think wisely, we adopted the other course. Speed, which incidentally we do not consider to be the only criterion of utility of aircraft free from some of the limitations of the aeroplane, will come as the result of stabilisation of general conception and of the concentrated efforts of a greater number of engineers. So will useful load, and while we make no claim to superiority in every respect, we are convinced that we will not be far behind the aeroplane in what might be called aeroplane performances.

To strengthen this assertion, I will quote an independent and authoritative opinion, that of Mr. John B. Wheatley, Aeronautical Engineer of the American National Advisory Committee for Aeronautics, who, in a paper he read last year to the Society of Automotive Engineers at Detroit, says literally that: "The majority of rotors in use in this country have a maximum lift-drag ratio of from 8 to 10 which occurs at a speed of about 100 m.p.h., though it is easy to show that values of from 12 to 15 may be obtained at higher speeds without serious difficulty and without materially sacrificing the low speed performance." Later, after reasoning that it is possible to design an autogiro with a range of speed as from 28 to 200 m.p.h., he goes on: "There is apparently ample reason for anticipating the development on an autogiro, in the near future, that will equal *or exceed* the high speed performance of the equivalent aeroplane, that is, an aeroplane of the same power and useful load."

Aerodynamical Progress

The most efficient rotor produced so far has a maximum lift-drag ratio (excluding the drag of the hub) of the order of between 13 and 14. This represents an increase of some 40 per cent. on the best rotor of five years ago, and perhaps 80 per cent. on the early autogiro rotors. At the same time, the maximum lift coefficients have been very materially increased. These results have been obtained by making the blades cantilever, suppressing the suspension cables, replacing the cumbersome interblade bracing by non-reactive dampers at their root attachment, using more efficient aerofoil sections, replacing the fabric covering which constituted a relatively irregular and deformable surface by a rigid superstructure, and by diminishing the solidity considerably.

The first two modifications belong rather more to the structural than to the aerodynamical improvements. They have necessitated in most cases the manufacture of special tapered high properties nickel-chrome steel tubes.

From the aerofoil point of view, the improvement has been brought by theoretical considerations. The aerofoils used in early autogiros were symmetrical, which sections are particularly sensitive to Reynolds number. As this last is comparatively small in the stalled sections, the symmetrical aerofoil makes a very poor autogiro blade.

The method for theoretically estimating the relative merits of aerofoils for autogiro work consists in calculating by graphical integration the average value of the profile drag coefficient for the range of incidences and relative air speeds covered by all the points of a blade in a complete revolution. Using this average

profile drag coefficient to make the account of total energy lost by friction, the profile drag for the whole rotor can be calculated. Estimating in an equivalent way or by ordinary calculation the average value of the lift coefficient for the range of incidences and speeds covered, and multiplying it by the average of the dynamic pressure for all points of the rotor and by the blade surface, the total lift is obtained. The ratio of the last to the first of these quantities measures the efficiency of the aerofoil considered for any given pitch angle and ratio of forward to peripheral speeds. Repeating the operation for different pitch angles and speed ratios, the result is obtained in every case that for the optimum pitch for every speed ratio the lift-profile drag ratio is almost constant for an extensive range of forward speeds, which is equivalent to saying that the total profile drag of the rotor is practically constant for most of the speed range. Another result is that, while the optimum pitch angle is not the same for different speed ratios, the lift-profile drag ratio corresponding to an average of the optimum pitch angles differs very little from the optimum.

The result will of course depend on the assumptions made when establishing the equations of lift, zero torque and dynamic equilibrium of the blade, but I have found that practically any reasonable assumption gives the same result.

The general conclusion I have reached, after analysing a large number of aerofoils on which reliable wind tunnel data are available, is that, in general, all-round good aerofoils for aeroplane use are good aerofoils for a rotor. I may add that experience so far seems to justify amply my theoretical results. The aerofoils now in use have been chosen not only by an efficiency criterion but by several other considerations. Their theoretical improvement on the symmetrical ones used before, is of the order of about 25 per cent., and the theoretically best aerofoils so far studied should be about 25 per cent. better than the present.

The improvement in efficiency due to smaller solidities is very important. Solidity in rotors has exactly the same influence in autogiro efficiency that aspect ratio has in aeroplanes. The early machines had solidities of the order of 0.2. Autogiros of a few years ago had about 0.1, and now solidities of the order of 0.06 are normally in use, while in one instance a value as low as 0.034 has been obtained, nearly six times smaller than the old values. The reduction in solidity has been made possible by a better knowledge of the strength requirements of the blades and refinements in their construction, and by the reduction of the number of blades—before always four, while now three-bladed rotors are standard. Many secondary problems of a dynamical nature were involved in the suppression of one blade, and, while the difficulties that a further reduction to two blades presents are of considerably greater magnitude, it is quite possible to expect it might be done in the future. Experimentally, and in certain conditions, satisfactory two-blade rotors have been produced.

When considering the aerodynamical progress effected, the suppression of the small fixed wing, made possible by the introduction of direct control, should be mentioned. The addition of the fixed wing was a decided improvement at the time, because the rotors in use were very inefficient. As in the lower wing of an ordinary biplane, that wing was affected by the downwash of the rotor and its lift-drag ratio considerably diminished; but, even so, it was better than that of the rotor, so that the combination improved the average. It is true that it meant extra weight, but, as in any case a transversal structure was necessary to support the ailerons, it paid to have it. The introduction of direct control and the aerodynamical improvement of the rotors altered the conditions, and a fixed wing in present machines would certainly not pay for its extra weight.

The most efficient machine built to this day reaches a top speed of nearly 110 m.p.h. and carries a useful load of nearly 500lbs. with an engine of only 75 h.p. The absolute maximum speed attained is about 125 m.p.h., and minimum speeds in level flight of the order of 15 m.p.h. have been obtained with very lightly loaded machines. The maximum altitude reached by an autogiro is of

the order of 21,000ft. Incidentally, and while this is of no scientific importance, I think it is interesting to point the anomaly that while the International Aeronautical Federation recognises all kinds of aeroplane and glider records, with special categories for different weights and even for women pilots, and helicopter records—purely experimental so far—are also given official status, autogiro records are not recognised. Figs. 1 and 2 show a 1925 and a 1934 rotor, as an illustration of the changes effected.

FIG. 1.

FIG. 2.

Dynamical Problems

Perhaps the most irritating of the secondary difficulties met with in the autogiro developments have been those of a dynamical nature. The dis-symmetry of speeds on both sides of the rotor produces periodical variations in the lift and drag and in the lift and drag moments on each blade. The articulations which allow the blades to flap, correct substantially the dis-symmetry of the lift moments as far as their average value at any rate, and an equivalent reason makes practically essential a second articulation which permits the blades a certain

freedom in their relative angular distances from each other. But, while the flapping motions are strongly damped by the variations in lift they entail, there is no appreciable damping in the horizontal oscillations, and this can produce important resonant phenomena and unpleasant free oscillations of relatively large amplitude following any impulsion—a bump for instance.

These free oscillations, which were well known to early autogiro pilots, produced a sort of irregular circular rocking motion which in America was known as " autogiro feeling " or " wobbling."

As some of the parameters entering into the equation of the horizontal oscillations are different whether the machine is on the ground before or after landing or in flight, and their values can be intermediate ones when the machine is partially air borne, it is very difficult if not impossible to design so as to be sufficiently far from resonant conditions in one state or another, and the artificial provision of damping means was one of the greatest advances in the field of secondary problems.

Until a few years ago, damping was effected directly between blades, but as this could only be done by elastic transmissions, as the variable coning of the blades upwards precludes any rigid attachments between them, there was no damping for small motions, and so the " autogiro feeling " could subsist in spite of inter-bracing of blades.

Finally the correct solution was introduced of effecting the damping in the relative independent motion between each blade and the hub. This suppressed the free oscillations, as well as resonance in any of the three possible forms of horizontal oscillation of the blades, but does not dispense with the necessity for choosing certain parameters suitably so that resonance, in flight at least, is sufficiently avoided—apart from the damping. Otherwise unpleasant vibrations are always present.

The flapping motion is aerodynamically damped, as said before, but the damping is of a periodical nature in any condition of forward flight, and so are the restoring moments, and in consequence the oscillation will not be a simple damped harmonic motion; and the possibility existed that, for relatively large values of the forward speed-tip speed ratio, the blade might become unstable in flapping.

The solution of the differential equation that represents the motion is of a very difficult nature and only surmises could be made on the probable stability of the blade. I am indebted to Professor P. Puig Adam, of the Escuela Superior Aerotecnica at Madrid, and some of his disciples, for a most brilliant analysis of that equation, which results in confirming that the stable conditions extend at least well beyond the practical range that can be covered. This study has been published in the revue " Aeronautica."

Apart from the oscillatory motions of the blades, the fact that they are finite in number introduces periodical variations of lift and drag, both in magnitude and in location, which are the origin of vibrations. Those vibrations become relatively important (accelerations of the order of one-tenth of the weight of the machine have been measured) if special precautions are not adopted in the design. The investigation of those vibrations and of their cure or mitigation has been a relatively major problem, particularly in relation to three- and two-bladed rotors, but we have now produced rotors in which the periodic variations of aerodynamical forces have been reduced to such an extent that practically perfect smoothness has been achieved.

The Engineering Technique

The structural and mechanical design shows an appreciable progress. Apart from all the modifications introduced in the rotor itself which have already been mentioned, hubs, hinges and mechanical starters have been very much improved in every respect in the last few years. The development of direct

control presented a large number of new problems in itself and in the more exacting requirements it introduced in the other mechanical parts. Fig. 3 shows part of the controls, hub and articulations arrangement of a modern autogiro. It can easily be appreciated that the machine as a whole partakes at least as much of the nature of a mechanical complex than of that of an aeroplane.

On the theoretical side, considerable progress has been made in the knowledge of the strength requirements of the blades. Their proper study involves what for a long time appeared to be insurmountable difficulties. The tensile stresses due to centrifugal force can, of course, be very easily estimated, and the torsional stresses (if proper precautions to avoid torsional resonances are taken) can be minimised to the point where they can be neglected, but secondary bending moments of a periodic nature are present in the vertical plane. Their value depends primarily on the laws of distribution of aerodynamical and inertia forces, and, if the blades were very rigid, here would the problem end. As it happens, they always are relatively very flexible and their deformation alters so con-

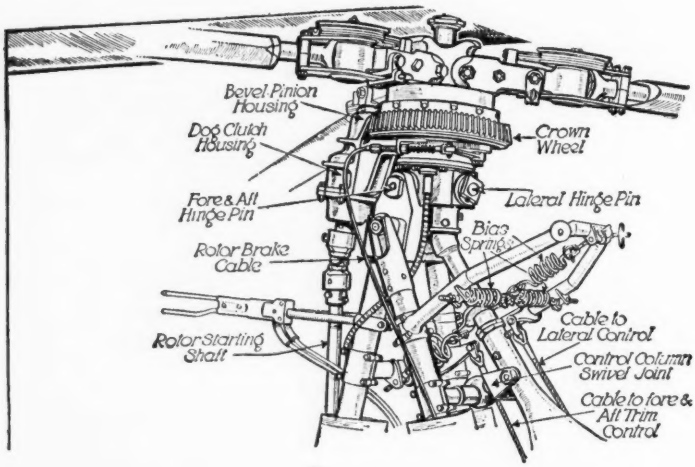

FIG. 3.

siderably the moments due to the inertia forces, always fortunately in the direction of diminishing the bending moments, that in many cases the flexibility reduces those moments by 75 or 80 per cent.

On the other hand, the flexibility of the blade introduces dynamic considerations, and the static values of the periodic bending moments can, in certain cases, be considerably magnified.

As far as the distribution of aerodynamical forces along the blade, reasonable assumptions can be made easily for the case of normal steady flight, but, unlike the case of the aeroplane, where the law of distribution of loads along the span is practically independent of forward speed and angle of incidence, there is a time element due to the inertia of the rotor which alters the law of distribution as well as the magnitude of the loads when sudden changes in incidence occur. That being so, the normal method of design, consisting in estimating the stresses in normal flight and giving them a load factor, would be meaningless in this case.

An analysis of the influence of the several parameters affecting the bending moments permits to determine the maximum values which any extreme manœuvre is likely to produce. That extreme manœuvre is assumed to be similar to the

one which would suddenly increase the incidence of the wing of an aeroplane to the angle corresponding to the maximum lift coefficient.

Once the bending moments are calculated on the assumption that the blade is absolutely rigid, the differential equation representing the deflected shape of the blade axis can be established, if the elastic characteristics of the blade are given. If that equation could be integrated, the radius of curvature at any point could be calculated, and from it the true bending moment. Unfortunately this is not the case, and I have been obliged to devise an approximate method consisting in integrating the differential equation on the assumption that the blade is perfectly flexible by making the product of the moment of inertia of the section by the elongation coefficient, or $I \times E$, equal to zero. The equation is immediately integrable and the radius of curvature of the perfectly flexible blade can be calculated. Multiplying it by the $I \times E$ product, an auxiliary bending moment is found. Calling it BM_t, and the bending moment for the same point

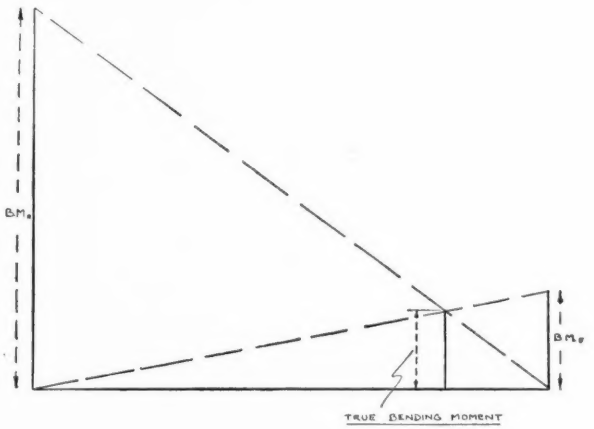

Fig. 4

of the blade assumed perfectly rigid BM_r, it can be shown that the expression $BM_r \cdot BM_t/(BM_r + BM_t)$ graphically represented in Fig. 4 gives a very close approximation to the true bending moment, particularly for its maximum values.

The magnification factor due to dynamic effects can be calculated by estimating the period of free oscillation of the blade when deflected in the approximate shape it adopts under the action of the bending moments, the aerodynamical damping introduced and, finally, by expanding the periodical bending moment, with time as the independent variable, into a Fourier series. The magnification factor corresponding to the amplitude of each harmonic can then be immediately calculated and also the difference of phase of the forced oscillation in that harmonic.

A graphical summation of the harmonics of the forced vibration gives a representation of the final bending moments, and the ratios of the positive and negative maximums to those calculated in the static assumption are the corresponding magnification factors.

This process is of course exceedingly elaborate, and a number of simplifying assumptions have to be made which are not of a nature that could substantially alter the results. Of particular difficulty is the calculation of the harmonics of the periodic bending moment with any degree of accuracy, since the third and

even fourth harmonics are of importance, but this can be done at least in the case corresponding to maximum stresses under the limiting manœuvres mentioned.

The most interesting conclusions of this study are that maximum bending stresses are almost independent of the weight of the machine, being a definite characteristic of each design of blade, and that they are also almost independent of the moment of inertia of the blade spar.

Measures in flight by means of extra light recording extensometers made by M. de Forest especially for the Autogiro Company of America, have substantially confirmed the conclusions of my theoretical analysis.

Fundamental Developments. Direct Control

After the sketchy summary I have given of the progress made in the general technique of autogiro design, I will briefly describe the successive changes introduced in the general conception.

Since the very first experiments I made nearly fifteen years ago, I had conceived the autogiro as a whole very nearly the same as it is to-day. Due to

FIG. 5.

imperfections of the technique of the then new art, and to the very great number of secondary difficulties, I had to abandon provisionally—and as it proved for quite a long time—my original conception and borrow from the ordinary aeroplane a sufficient number of elements to permit me to get my machines into the air and systematically improve the rotor, their basic element.

When I had obtained a rotor sufficiently free from vibrations, I returned to my first ideas, and since the early months of 1932—after I had developed a theory as complete as possible with the information I had then—an experimental machine, wingless and at first tailless, was flown (Fig. 5). As was to be expected, a number of secondary problems appeared, but except for the necessity of replacing the tail, without which flying was difficult, while possible, the machine behaviour was in very good agreement with the expectations.

Apart from the minor problems, mostly of a mechanical nature which had to be solved, the greatest fault of the experimental machine was the action of the engine torque. As it was then corrected by deviating the rotor lift laterally so as to create a gravity-lift torque, the correction depended, for a given control

setting on the instantaneous lift, and as in bumps and manœuvres, turning, etc., the lift changes, so did the correction, introducing a most disconcerting rolling motion. The correct solution obviously lay in compensating the engine torque by aerodynamical forces independent of the lift, and a simple and practical way was found which consisted in giving a differential incidence or a differential camber to either side of the tail, so that, in conjunction with the rotary component of the airscrew's slipstream, the desired compensating torque is created. Theoretical considerations proved that the correction would be almost independent of forward speed, and experience demonstrated this to be the case. Fig. 6 shows the torque-correcting tail.

I will not go here into the theory or the results obtained with direct control. It is now well known generally that, since its introduction, the autogiro—homogeneous for the first time—can make full use of its inherent qualities, the most obvious of which are its controllability at slow speeds and its ability to land at practically no forward speed. There is no question as to direct control being the correct one for autogiros, and I venture to predict that, in that respect

FIG. 6.

at least, no further fundamental progress will be made, while it can be, naturally, considerably improved in detail.

Suppression of Rudder

As a consequence of the introduction of direct control, the rudder has been successfully suppressed in certain types of autogiros. It is true that there are aeroplanes that can normally be flown without a rudder, but at slow speeds and in certain cases of landing, for instance, the rudder is necessary. Direct control autogiros are in an entirely different position for a variety of reasons. One is the absence of the fixed wing, with its differential aerodynamical torque opposing the rotations around a vertical axis. Another, more important still, is that the lateral control is obtained by a lateral force above the centre of gravity which, on being applied, creates a rolling torque and gives a transversal impulse simultaneously, so that a sideslip is initiated at the same time as a lateral rotation—instead of afterwards, as would be the case with aileron control. This makes possible turning almost correctly, provided the machine has a sufficient degree of directional stability.

One of the useful functions of the rudder in aeroplanes is to allow side-slipping—a very good way to increase the steepness of a glide. Autogiros can glide at all steep angles at will by simply pulling on the longitudinal control, so sideslipping is altogether unnecessary.

Even in the case of landing in drift, much more appreciable at the slow speeds at which an autogiro makes contact with the ground, the rudder is unnecessary if the proper autogiro technique is used. This is not in my opinion a disadvantage, since, while it might surprise at first pilots with aeroplane experience, it forces them into learning the correct way to drive an autogiro, and so make better use of it.

As I do not wish to be dogmatic on this point I will say that, while perhaps more than some four thousand hours flown by dozens of different people on rudderless direct control autogiros prove the perfect feasibility of the suppression as a practical proposition, it is quite likely that for certain types of machines, or for certain types of utilisation, a rudder might be an advantage and even a necessity. But the almost unanimous opinion of the many who have flown the new machines long enough to be familiar with them is that the simplification introduced is a definite advantage.

Direct Take-off

In the same way that the general progress of the autogiro technique and the relative perfection of the rotor made possible since 1932 my original conception of direct control, the perfecting of direct control made in its turn possible to contemplate, since the end of the same year, the realisation of another idea of the old days. If by some means the pitch angle of the blades is substantially reduced to zero during the process of starting the rotation by the application of mechanical torque to the rotor, the drag torque is diminished considerably and the lift is eliminated. Both facts allow the rotor to reach an initial angular speed very much in excess of the one corresponding to normal flight. If, simultaneously with the declutching of the mechanical transmission, the pitch of the blades is increased to its normal value, lift is instantaneously generated; and, provided it exceeds the weight of the machine, this will leave the ground at a steep angle (not necessarily in a vertical trajectory), will hover for a moment, and initiate a descent afterwards as the rotational speed rapidly decreases. But if the traction of the airscrew has provided an impulse of sufficient importance to impart to the machine during the upward motion at least the minimum horizontal speed at which it can keep level flight, it will not fall back to the ground but will continue the flight initiated by the jump. This process could be improved if the lift given by the rotor were inclined forward slightly so as to give a negative drag at first.

In this way a take-off without any forward run seemed possible, giving the autogiro the one quality which might otherwise appear to be the preserve of helicopters or similar direct-lift machines.

I have the honour of making public here for the first time that this result is now fully achieved. As a matter of fact, I succeeded in leaving the ground without run as far back as August, 1933, but the usual secondary troubles did not allow the system to be sufficiently developed to give absolutely conclusive results until some five months ago.

The experimental machine, of a very crude design, was not really intended to give a good performance in leaving the ground, but was more in the nature of a test bench to investigate the principle itself and to perfect the mechanisms used. In spite of this, it is perfectly capable of leaving the ground in no wind with the chocks in front of the wheels. The initial height obtained is only a few feet, but quite sufficient for the purpose.

I want to make perfectly clear that the results obtained, while absolutely conclusive are still experimental, and prudence forces me to refrain from making

any forecast as to how soon they will be obtainable in a practical way. The eighteen months of development have given us a thorough insight into the theoretical aerodynamics of the new effect, together with a considerable experience of its practical side.

All our conclusions will be incorporated in a new experimental machine, which not only should show a very improved performance but which ought to be free from the secondary imperfections of the first one. Until the new machine has been thoroughly tested, nothing more can be said about this development. I will only mention that the mechanism used for the pitch change involves no addition whatsoever to the existing elements of normal direct control autogiros, consisting substantially in a tilt of the drag hinge in a vertical plane containing the axis of the blade, and that it operates automatically by the mere application of the starting torque in the usual way. Also, the actual manœuvre from the pilot's point of view is a very simple one, easier and more pleasant than an ordinary take-off.

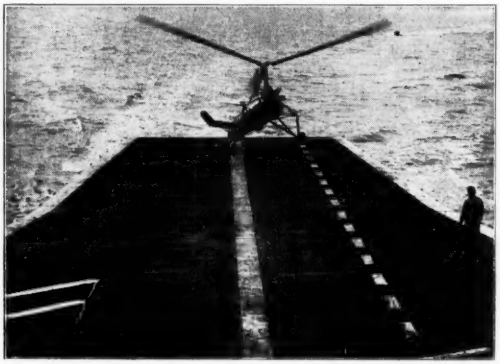

FIG. 7.

The Industrial Development

Until last year no autogiro industry had existed in this country. Last summer, however, Messrs. A. V. Roe and Co., Ltd., took a licence and started the manufacture of the two-seater C.30 type. A relatively large number of these machines are now in service, not only in Great Britain but all over the world. Its description has been amply published, and it will be unnecessary for me to say any more about it.

A number of new machines are being developed, both here and abroad. There is a five-seater machine with a Panther engine; two side-by-side cabin autogiros with Pobjoy engines, one here and the other in the U.S.A.; a small single-seater, and several machines of a more or less military character.

It is hoped that production of autogiros will soon be started in France, and perhaps in some other Continental countries.

Progress of the Application

During the last twelve months a good many possibilities have been explored and demonstrations given with a view to opening several interesting avenues.

Apart from a number of private owners, commercial concerns and flying clubs, many governments have purchased a number of autogiros with a view to investigating their potential applications for military, naval or police work.

It is not generally known here that an autogiro has already been used, very

successfully, in actual military operations. It belongs to the Spanish Navy and its pilot could, thanks to the peculiar characteristics of the machine, fulfil successfully a number of important missions in the mountainous province of Asturias during the October rebellion last year.

The potentialities of the autogiro for observation, liaison work, and as a staff car, are now generally recognised.

As far as naval applications, important demonstrations have recently been given. A year ago I myself landed and took off again from the deck of a Spanish transport ship, at anchor in both cases. The available room was about 40ft. by 130ft., and I had no real difficulty. More recently Mr. Brie, the chief pilot of the Cierva Autogiro Co., Ltd., succeeded in landing to and taking off from a still smaller platform installed above the after deck of the Italian cruiser "Fiume." He did it a number of times and in different conditions, from the ship at rest to steaming 24 knots. Fig. 7 shows the machine landing on the "Fiume."

The Future

The near future should see a very rapid progress of the autogiro in every direction. We have now developed the technique of the art to the point when what might be called "unfavourably compromising" in the design ought to become unnecessary. Detail refinements will no doubt be quickly attained, and the predictions quoted at the beginning of this paper will be fulfilled.

The ability of the autogiro has been doubted to reach speeds of the order of 200 m.p.h. without losing considerably on the slow side of speed. That is quite definitely not so, and to prove it, it will suffice to point out that the rotor of the standard C.30, with only secondary modifications, could be used appropriately in a machine of the same weight but clean enough and with enough power to attain some 160-170 m.p.h. The efficiency of a rotor is practically constant over a large range of speeds, and at those mentioned that rotor would be, if anything, more efficient than at the present maximum speeds of utilisation of some 100-110 m.p.h., while at slow speeds the performance of the rotor would, of course, be identical to those extant.

The development of direct take-off will undoubtedly enormously amplify the field of application, and while the autogiro will have many of its own, direct take-off and the attainment of high speeds will make it competitive—at the extreme ends of its range—with both aeroplane and helicopter. This last in particular should become, even assuming a helicopter that works is really developed, of doubtful practical interest.

Direct take-off will allow the use of fields with any kind of surface—ploughed, stony or marshy. When fully developed, it will permit autogiros to jump high enough to clear any number of ordinary obstacles—small houses, trees, etc.—from a distance of only a few yards. Jumps up to heights of the order of 60ft. to 100ft. are theoretically possible without reaching prohibitive accelerations, but I believe that for practical purposes an initial height of some 20ft. is the maximum required.

As to seaplane and amphibian applications, direct take-off should offer very interesting and obvious possibilities.

There is so much talk nowadays of roof landing and aerodromes in cities that I prefer to deal with the subject myself rather lightly. But I can say that I consider them as practical propositions in certain cases at least. Flying to and from small platforms on board ship is a much more difficult thing, and yet it has been achieved successfully.

Imminent improvements in various directions will make roof landing a perfectly safe manœuvre, and I can say we are ready to study from now any form of application involving flying from small platforms or reduced enclosed spaces.

The first of the three cinematograph films by which the paper was illustrated was made from a number of news reels taken during the last two years on the occasions of presentations of direct control autogiros; it constituted a graphical résumé of the results achieved in the last two years or so. It showed the first C.30 that was built, and the commercial type that was developed from it; and finally it showed a take-off from a landing on the deck of a Spanish transport ship, effected by Senor Cierva himself. A landing was made without the use of the engine.

The second film showed two take-offs at normal film speed, and two take-offs in slow motion. In none of the four take-offs did the machine move forward at all before leaving the ground; to ensure that there should be no forward movement, blocks were placed in front of the wheels.

The third film was one taken by Squadron Leader Hillier, showing the autogiro taking off, flying and landing.

The PRESIDENT: On behalf of the Society, he expressed thanks to His Excellency, the Spanish Ambassador, for having attended the meeting. It was only right, he said, that His Excellency should be present to see how much the Society welcomed the efforts of that very distinguished son of Spain, Senor Cierva.

DISCUSSION

Mr. H. E. WIMPERIS (Director of Scientific Research, Air Ministry): Ten years had passed since Senor Cierva had brought his wonderful invention, the rotating wing autogiro, to this country; during that period he had disclosed to the Society the gradual development of his direct control autogiro, and on the present occasion the "jumping autogiro." It was a compliment to the Society that he had waited until this meeting to make this first disclosure in public. It could not have been an easy matter to avoid disclosing it before, because, after all, an aerodrome was a somewhat public place, and Mr. Wimperis knew from personal experience the difficulties he had had. When Senor Cierva had kindly asked a Member of the Air Council and Mr. Wimperis to see the jumping autogiro it had been necessary to make a start before the sun had risen and to see the autogiro rise with the sun. Mr. Wimperis had been very much impressed with the startling success of that demonstration and so had the Member of the Air Council whom he had accompanied.

The latest form of jumping autogiro did provoke, as the inventor had said, direct comparison with the many attempts made to build helicopters. Many Governments had been exceedingly interested in the problem, and fifteen years or so ago the British Government had offered a prize of £50,000 to anybody who could produce a helicopter which could do certain rather simple things. There had been no actual entries at that competition. But as so many countries had tried to produce a helicopter, it was worth while considering what were the differences between the jumping autogiro and the helicopter pure and simple. The new autogiro had shown that it could give a vertical take-off. That was important, because the obstacles on the ground were the things they wanted to get away from and it was the first few feet that counted. The films had shown how the autogiro could leap up, even though chocks were placed in front of the wheels. Previously, on an aerodrome, one had felt quite safe when on the right side of the chocks; but nowadays that was not to be so. They had known that the autogiro could accomplish hovering flight on any day in any probable wind, because, whatever its speed, whether it were 15, 20, 25 or 30 miles per hour, there was at a height of even a few thousand feet a probable wind of a magnitude which meant that the ground speed would be substantially zero if the head of the machine were in the right direction. So that probably on any day one could actually hover in an autogiro; and they knew also that with the machine which had been illustrated they could achieve vertical take-off as well. Senor Cierva

might well feel that there was not much left in that particular field for him to win. It did not go absolutely the whole way towards all a true helicopter could do, but it went a very long way, and on that achievement the Society offered him the most sincere congratulations.

Reference had been made to the convenience of this method for taking off seaplanes, and certainly if one could diminish the long run and the repeated encounters with waves, the problem of taking off would be greatly simplified, the strength of the hull need not be so great, and therefore, its weight could be reduced. All that was to the good. But Mr. Wimperis did not think that a picture of a seaplane sitting down on the sea and then taking off straight away was quite the right picture. There must be enough steerage way to ensure that the reaction from the engine in working the rotor did not turn the hull in the opposite direction, and he asked what Senor Cierva considered to be the necessary speed to the taking off point.

On the general subject of this new experimental development, Senor Cierva was to be congratulated, and Mr. Wimperis was sure that his department would wish to enter into the experimentation with Senor Cierva.

Mr. J. G. Weir (*Fellow*): Having had the honour and privilege of being associated with Senor Cierva in some of his work, he assured the meeting that Senor Cierva's genius was most remarkable in its versatility. He was a mathematician, an aerodynamist, an engineer and a constructor; and, with all that, he possessed a tremendous fund of common sense and a very perfect sense of proportion, as well as a genial and marvellous personality.

Coming to the fundamental aspects of Senor Cierva's work, Mr. Weir pointed out that the problem underlying heavier-than-air flight was simply that of imparting an acceleration to certain air masses, thereby obtaining a reactive force upwards. The magnitude of those forces depended on the mass of the air to which could be imparted that acceleration. Using a fixed-wing machine, one could reach the air only by moving the whole machine forward. The rotating-wing machine was a direct frontal attack on the problem of obtaining more air to deal with, without necessarily moving the apparatus. Aircraft development during the past few years had followed broadly the lines indicated in the paper by Professor Melville Jones some years ago. The enormous development in speed had been practically a question of reducing parasite drag. Associated with that there had been all the various methods of minimising the other fundamental limitations. They had every possible form of maintaining lift at low speeds and of minimising the effect of necessarily high landing speeds, such as wheel brakes, and things of that kind. Mr. Weir suggested that aviation had possibly reached a turning point, and that in the immediate future more attention would be paid to this direct attack on the problem of flight. All the ground won for them in the fixed-wing machine could be applied equally to the rotating-wing machine, and in his view the importance of encouraging this fundamental research was very great indeed. He paid a tribute to the Director of Scientific Research at the Air Ministry for the continuous encouragement and assistance he had given.

Finally, commenting on the remark that it might be necessary to provide steerage way on the direct-lift seaplane before taking off, Mr. Weir suggested that if a good big rudder were fitted to the machine, to hold it against the slip-stream, that might possibly solve the problem.

Colonel Mervyn O'Gorman (*Fellow*): They had been thoroughly interested, and even amazed, by the progress which Senor Cierva had achieved within a short period, and they were grateful for the remarkable exposition he had made of his latest autogiro's power to jump. Senor Cierva had alluded in a passing way to his former desire that the F.A.I. should institute a separate class for records open only to the possibility of the autogiro, that is to say, a class that would take it out of competition with aeroplanes as helicopters are. Surely, the

greatest compliment that could be paid to the autogiro was to admit that it was fit and competent to carry away the laurels from the normal aeroplanes in open contest. That compliment had been paid it. Moreover, that was not an empty compliment from the International Aeronautical Federation, because, as Senor Cierva would recall, the autogiro had received the highest award that could be given internationally, namely, the gold medal for the best achievement in aeronautical progress made in a given year in the world. One could therefore hardly say that the autogiro had not been handsomely recognised by the F.A.I. At the date when application was made for the autogiro to be given a separate classification, it utilised, as Senor Cierva had mentioned in his lecture, so many of the aeroplane's functional structures that it was at that period difficult to phrase any legislation to distinguish it as a class from an aeroplane with any little rotor on the top. Surely it was undesirable that the F.A.I. should specify such details as the size of the rotor necessary to distinguish the class, yet without that the difficulty of making a line of demarcation was almost insuperable. Now, however, the design of the autogiro and the consequent position had changed; Senor Cierva had abandoned the use of wings and other characteristic aeroplane elements. Accordingly Colonel O'Gorman suggested that if Senor Cierva still wanted the F.A.I. to institute an autogiro class—which was very doubtful—should he apply again he would probably succeed. Colonel O'Gorman added that he had been concerned for 25 years with one of the most interesting but also the most thankless of unpaid tasks, that of international sports control. Its sole object was to provide means for the light of super-excellence to shine forth. For this task one received no thanks, no pay, and no honour, but plenty of kicks; chiefly because the kickers rarely knew how intricate a job it was. He could understand that Senor Cierva might want some contest to be organised which would enable the astonishing feats of the autogiro to be made clear in open contest. If so, let him suggest that there be a " range of speed " competition and indicate in what way this valuable but extraordinarily difficult qualification to assess in a contest might be reliably measured. He must remember that it would have to be measured not as a scientific research—that was easy—but by the somewhat amateurish secretaries and officials of some 37 sport controlling bodies in every part of the world. This would no doubt mark the institution of yet one more kind of world record—and there existed already provision for several hundreds, viz., according to speed, weight carried, height, distance, size of aircraft, sex of pilot, etc. There was no doubt at all that a performance of descending like fluff and yet jumping up like a flea was immensely creditable, and he congratulated the author as well as thanking him.

Mr. BRIE: All present at the meeting had heard and seen something which possibly they would never forget. However, the film did not convey all that direct take-off meant. One had actually to see the take-off in order to believe it—and, having seen it, one could not believe it. He took the opportunity to pay his tribute to Senor Cierva, who had accomplished the seemingly impossible.

Mr. E. F. RELF (Superintendent of Aerodynamics Department, National Physical Laboratory) (*Fellow*): He did not think even the most sanguine, at the time experiments in connection with the autogiro were first commenced at the Laboratory, could have believed that the autogiro would have developed to the stage reached to-day. That development was due, of course, to the work of Senor Cierva; no degree of admiration could be too great in respect of that work and of the way he had, single-handed, as the President had said, brought this venture to such a satisfactory stage.

There were still plenty of things about the autogiro which we did not understand, from the theoretical point of view; but the same could be said of the simple fixed wing. They did not understand the phenomena of maximum lift or even of minimum drag; and the autogiro wing was essentially more complex, because it rotated and the blades had individual motions of their own, apart

from the forward motion. A good deal of work was done at the National Physical Laboratory some years ago, and at the Royal Aircraft Establishment, mainly by the late Mr. Glauert, at Farnborough, and Mr. Lock, at the National Physical Laboratory, on the theory of the rotating wing, and experimental work had been done in the wind tunnel. That experimental work had been rather difficult, because the behaviour of these wings was very sensitive to scale effect; the nice condition of equilibrium which settled the rate of auto-rotation was very dependent on the scale effect on the drag of the blades, and therefore, it was very difficult to get perfect experiments on the small scale—there were no large tunnels in this country at that time. He hoped that in the future some experiments might be carried out in the large tunnel at Farnborough, for instance, where there was a better chance of investigating the theory. Using modern values of profile drag and such quantities, one was fairly happy with the theory in the ordinary ranges of flight; but there were two conditions in regard to which one was not happy, *i.e.*, the slowest flight of which the autogiro was capable, where one was not sure how to treat the system theoretically, and also at very high speed. Mr. Relf asked if Senor Cierva was considering the publication of his own theoretical work, for it was quite obvious from the few remarks on the subject in the paper that he had done a great deal more work than anybody else had seen, and those concerned with the theoretical side of the problem would be interested to read it.

Finally, Mr. Relf asked if Senor Cierva thought there were any dangerous conditions into which an autogiro could get. Were there conditions of motion in which control might be difficult, such as, for example, a dive with the rotor inclined at a steep angle?

Professor G. T. R. Hill (*Fellow*): There was a very grave omission on the part of those who had enumerated some of Senor Cierva's outstanding qualities, for among the most important of his many fine qualities was his boldness and skill as a pilot. Professor Hill commented with satisfaction upon the enthusiastic manner in which the meeting had acclaimed this latter quality, because without it Senor Cierva would never have progressed anything like so far as he had. The landing he had made on the deck of a ship, as shown in the film, was most extraordinarily impressive.

This country was indeed fortunate in having lured Senor Cierva here, with the result that they were the first to receive the news officially and publicly, of his most remarkable new work. The vertical ascent, which the meeting had seen illustrated in its early stages, was surely only the beginning of what one looked forward to seeing illustrated, possibly before the Royal Aeronautical Society, a few years hence.

Professor Hill recalled having witnessed the early trials at Farnborough in 1925, which almost carried one back to the early days of aviation when one would lie on the grass in one's anxiety to see whether the wheels would actually leave the ground. It was, of course, in advance of that stage; but, relative to the performance of ordinary aeroplanes at that time, the autogiro was far behind, as Senor Cierva would probably admit. Without doubt, however, he was rapidly catching up, " blade over blade," and one might look forward with confidence to high speed.

Mr. E. C. Gordon England (*Fellow*) (Member of Council): A paper such as that presented by Senor Cierva was a joy to those who suffered from the possession of rebellious spirits. Many present at the meeting could be classed, with himself, as rebellious spirits, who hated the common or garden and the attitude of mind which led people to say, " We now know all about it." It was refreshing to hear the reading of a paper which showed that they knew nothing, relatively, about anything and that the whole field lay ahead of them. Even if Senor Cierva had done nothing else by presenting his paper, he had given the

meeting extra heart and encouragement to combat those who tried to pretend that they had achieved some real distinction in the air up to the present time.

Mr. Gordon England was rather sorry to hear references to the " jumping autogiro." Those who were better linguists than himself could no doubt think of a very euphonious expression for " grasshopper," for he suggested that " grasshopper " would be a more pleasant title; it was extraordinary how closely the take-off of the autogiro followed the take-off of the grasshopper.

But it was a matter for great regret that the autogiro presented, so far as its accommodation was concerned, all the worst aspects of the aeroplane; he would like to know why Senor Cierva had made it as awkward as he had done for the occupant of the autogiro. One felt that he was missing a great opportunity. There was no earthly reason why he should follow all the worst characteristics of the aeroplane in that respect; one would have thought that he had an unlimited field to make a really comfortable vehicle for the human being. It seemed that technically he had approached distinctly nearer than had anyone else to " Mr. Everyman's aeroplane "; but Mr. Everyman was apt to judge everything more from the point of view of personal comfort and convenience than from any other point of view, and Senor Cierva's autogiro seemed to fall lamentably short of what the man in the street wanted in that respect. There must be some very good reason why he had not dealt with that aspect, and one hoped that he would deal with it faithfully and fully in his reply.

Mr. A. G. v. Baumhaeur, Amsterdam (*communicated*): The lecture he attended with great pleasure and had admiration for the speaker's achievements, but did not think it was appropriate to raise a certain technical question. He was pleased to take the opportunity offered by the President to put a question in writing.

It deals with the control and stability of the autogiro type C.30a.

When flying at a range of speeds it has been observed that the balancing force to be applied at the control column in the longitudinal direction increases with the speed and is directed backwards. This slope of the curve of control force against speed is opposite to that found for longitudinally stable aeroplanes and indicates longitudinal control instability.

He added that on a flight test he found that for speeds above 40 m.p.h. the position of the control column was practically independent of the speed; thus the elastic bias could not influence the slope of the force-speed curve.

He would like to ask Mr. de la Cierva what he intended to do to improve this quality.

Professor Alexander Klemin (*communicated*): A useful footnote on Senor Juan de la Cierva's admirable paper might lie in the recent announcement of the Department of Commerce in the United States. A direct take-off autogiro naturally makes possible the use of smaller aerodromes than hitherto. In fact any plot of land becomes a potential flying field. It becomes all the more important, therefore, that the autogiro should have the easiest means of transportation. The Department of Commerce, with this in view, has placed an order with the Pitcairn Autogiro Corporation for a two-seater cabin autogiro capable of travelling under its own power over the roads. The engine is to be placed at the back of the passengers. While the problem is evidently of some mechanical complexity it is not unsolvable. It may be remembered that in 1921 M. Renée Tampier developed the " Avion " automobile, which navigated the streets of Paris successfully and flew equally successfully. In the Tampier automobile an auxiliary engine was used in the ground transmission. In the autogiro ground transmission, it may be surmised that the main engine will itself be used with clutch, change of speed and differential transmitting power to the wheels.

It is most gratifying to see how progress may on one side of the Atlantic immediately give impetus to effort on the other side of the ocean.

Mr. W. E. GRAY (*communicated*): He would like to congratulate Senor de la Cierva on the brilliant simplicity with which he has made the take-off automatic and so saved the pilot any added complications, for that seems a very valuable feature. He would also like to urge him not to accede to Mr. Relf's request to publish all his results, lest he should find himself hampered by " red tape " once the Ministry feels it knows as much as he does. He owes it to an already grateful world to keep his hands free.

REPLY TO DISCUSSION

Senior CIERVA, commenting upon the fact that Mr. Wimperis had thanked him for having waited until this meeting of the Society was held in order to disclose his results, said that he saw no other way of thanking the Royal Aeronautical Society for the very great honour it had conferred upon him in electing him a Fellow. He also pointed out that Mr. Wimperis was responsible for the first demonstration of the autogiro in this country and very probably also for his presence on this occasion.

With regard to the direct take-off of the seaplane autogiro, there were a number of possible solutions. If there were any objection to creating steerage way of the order of perhaps 8-10 m.p.h. there were methods such as that indicated by General Weir of using the slipstream from the airscrew. Anyhow, he did not think that was a major problem.

In thanking Colonel O'Gorman for his remarks, he stated he did not wish to quarrel with the International Aeronautical Federation; he would not dream of quarrelling with the entity which had conferred upon him the greatest possible honour that an aeronautical man in any part of the world could enjoy. He really had never been very much perturbed about matters referred to, but merely wanted to point out what appeared to him an inconsistency. As to any distinction between an aeroplane and an autogiro, one might specify autogiros having fixed wings of less span than rotor diameter for example, or make distinctions of that sort. However, he was not out for record breaking.

Senor Cierva was unable to reply definitely to Mr. Relf's question as to whether he would be prepared to publish more of his work. The answer to the question as to whether the autogiro might get into a dangerous condition depended entirely upon its particular design. The rotor might tend to exhibit some abnormal characteristics when approaching very high ratios of forward and peripheral speed, but there were only indications of what would happen. It was likely that vibration would increase with the ratio. From the practical point of view, and so far as he knew, there was no danger in diving an autogiro except in case of certain peculiar characteristics due to individual design; but if it were discovered that in certain conditions it would be dangerous for the autogiro to dive steeply, it would be possible to devise means of preventing the pilot diving the machine at a dangerous speed.

After thanking Professor Hill for his compliments, Senor Cierva said he hoped the name " grasshopper " would not be adopted for the direct take-off autogiro, as suggested by Mr. Gordon England, since in the Spanish language it would sound rather undignified.

The problem of providing more comfort in the autogiro would probably receive more attention as soon as a closer approach was made to finality with regard to aerodynamical and structural design. He personally had been concerned more with the fundamental aspects from the aeronautical point of view, but there were autogiros built, and some already flying, which he believed would satisfy even the most exacting requirements.

In answer to the written contribution to the discussion of Mr. A. G. v. Baumhaeur, Senor Cierva states that the C.30, which is to all intents and purposes the first " direct control " autogiro, while being a most useful and successful machine, cannot be considered by any means as perfect and there are

a number of points on which improvements are desirable. He assures Mr. v. Baumhaeur that the peculiarity he has noticed is an entirely particular one to that machine, but as to the means that can be used to improve it in that particular respect, he is not prepared to broadcast at present.

He thanks Professor Alexander Klemin for his complimentary remarks and would like to take advantage of this opportunity to thank his collaborators on the other side of the Atlantic who have contributed so much to the development of the autogiro. The " autogiro-automobile " might, when fully developed, result in one of the most sweeping changes in locomotion.

Senor Cierva desires to thank Mr. W. E. Gray for his flattering remarks and his advice, and he can assure him that whatever information he publishes he will take great care that it is not of a nature such as that publication could hamper his activities.

The PRESIDENT: Proposing a vote of thanks to Senor Cierva, he said he had been delighted to hear the tribute so generously paid him by Captain Hill, because the practical flying part of the development of the autogiro had been of immense value. It was his ability and courage, not only in dealing with the theoretical side of the work, but in getting into the actual machine and flying it, that one admired so very much. The President also paid a tribute to Mr. Brie.

He confessed that he was reaching a stage in life at which, the more he knew about aviation, the less desire he had to go into the air; no doubt that was a trouble afflicting many people, and they wanted very soon a " safety bicycle." He did not think Senor Cierva's invention would become an actual rival of the aeroplane—it was complementary to the aeroplane—but there was an enormous demand throughout the world for something in which the " mug " could fly, so that one could make many mistakes, the gravest penalty for any of those mistakes being that one would go to the hospital rather than to the cemetery. The President hoped that the desire of the private individual to get into the air with a certain amount of safety would be Senor Cierva's chief consideration in the future—and not great enterprises and commercial exploitation. It was interesting to think that probably, in the realms of the great " urgers on " of aviation, there would be writ large the name of Mr. Hore-Belisha! Surface transport would become impossible, so that they would have to take to the air—and he hoped sincerely that they would do so in Senor Cierva's machines. Whilst congratulating and thanking him, the President hoped that the Society might have the advantage in the future of hearing of his further developments.

THE CORROSION OF ELEKTRON ALLOY AM 503 BY LEADED FUELS

PART I.—MECHANISM OF ATTACK

BY

G. D. BENGOUGH, M.A., D.Sc., and L. WHITBY, Ph.D., M.Sc., A.I.C.

Tetraethyl lead is a constituent of most fuels of high anti-knock value, but such fuels cause serious corrosion of magnesium-base alloy tanks and may completely penetrate them in a few months.[1] No work on the mechanism of this attack has been published and no satisfactory method for protection exists, so that magnesium-base alloy tanks cannot be used for leaded fuels. Since tanks constructed from an ultra-light alloy would be of advantage for aircraft, experiments have now been carried out to elucidate the mechanism of their corrosion, this work representing the first stage of an attack on the problem of providing protection against such corrosion.

Wrought sheet Elektron AM 503 alloy (Mn, $\geqslant$ 2.5 per cent.; Al, Zn and Cu, $\geqslant$ 0.2 per cent. each; Si, $\geqslant$ 0.4 per cent.; Imps., $\geqslant$ 0.5 per cent.; Mg remainder) to specification D.T.D. 118, the most suitable magnesium-base alloy for tanks, since it can be welded, has been used in the form of specimens 4 × 18 cms. All metal was pickled in 10 per cent. nitric acid before use and the specimens were immersed in various fuel mixtures contained in glass vessels, 28 of which could be held in a mechanical shaker and shaken at the rate of about 40 times per minute through an arc subtending an angle at the axis of "rotation" of approximately 150°;[2] Fig. 1 shows the type of vessel used. Standard amounts of 150 ml. of the undoped petrols were used in the vessels and resulted in about 7.5 cms. of the specimens projecting above the surface of the liquid. The shaker was kept in a shed where it was exposed to the open air and during the course of all experiments daily maximum and minimum temperature records were kept.

For military purposes the maximum allowable concentration of tetraethyl lead in any fuel is 7.0 ml. per imperial gallon. In practice tetraethyl lead is mixed with ethylene dibromide in order that the lead may be evacuated with the exhaust gases as volatile lead bromide. The mixture employed for adding to aviation fuel is known as "I-T Mix" and is composed of the following constituents:—

Tetraethyl lead	61.42% by weight.
Ethylene dibromide	35.68% ,,
Blue dye	0.17% ,,
Kerosene and impurities... ...	Balance.

In order to increase the rate of attack, the amount of "I-T Mix" has been increased in our experiments to 3 ml. per 150 ml. of petrol. This procedure can only be justified if a linear relationship exists between the amount of corrosion and the amount of "I-T Mix" present in the fuel. In order to test this point experiments were carried out in duplicate, each pair with a straight-run paraffin

[1] See, *e.g.*, Banks, *J. Roy. Aeronaut. Soc.*, 1934, **38**, 309.

[2] A new shaker has now been constructed to hold sixty vessels and to give a horizontal shaking motion.

type aviation petrol with 5 ml. of water added, the volume percentage of " I-T Mix," however, varying from 0.1 to 3.0.

Weighed specimens were immersed in these mixtures for fixed times of four and six weeks respectively, and at the conclusion of the experiments the corrosion

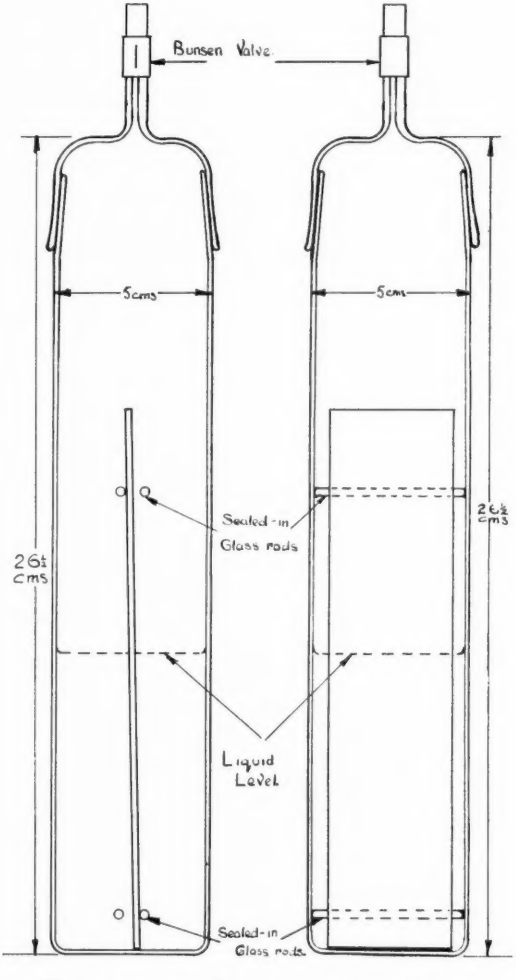

FIG. 1. Corrosion Vessel containing Specimen.

product was dissolved by means of a boiling 20 per cent. chromic acid solution, containing silver chromate[3] and the losses of weight determined. The results are shown in Fig. 2, and except for small concentrations of " I-T Mix " a linear relationship between loss of weight and volume percentage of " I-T Mix " was

[3] Whitby, *J.S.C.I.*, 1931, **50**, 83T.

given. All points on the curves represent the mean of duplicate experiments. In connection with these and all additional experiments it should be stated here that since the vessels were not thermostated no two batches of experiments are comparable, although, of course, individual experiments of each batch are strictly comparable with each other.

The range over which the linear relationship holds appears to depend on the total time of immersion and is slightly less when reduced from six to four weeks. This is probably caused by the fact that the rate of corrosion varies not only with the " I-T Mix " content, but also with the liquid water content. After corrosion has commenced, some of the water is used up to form magnesium

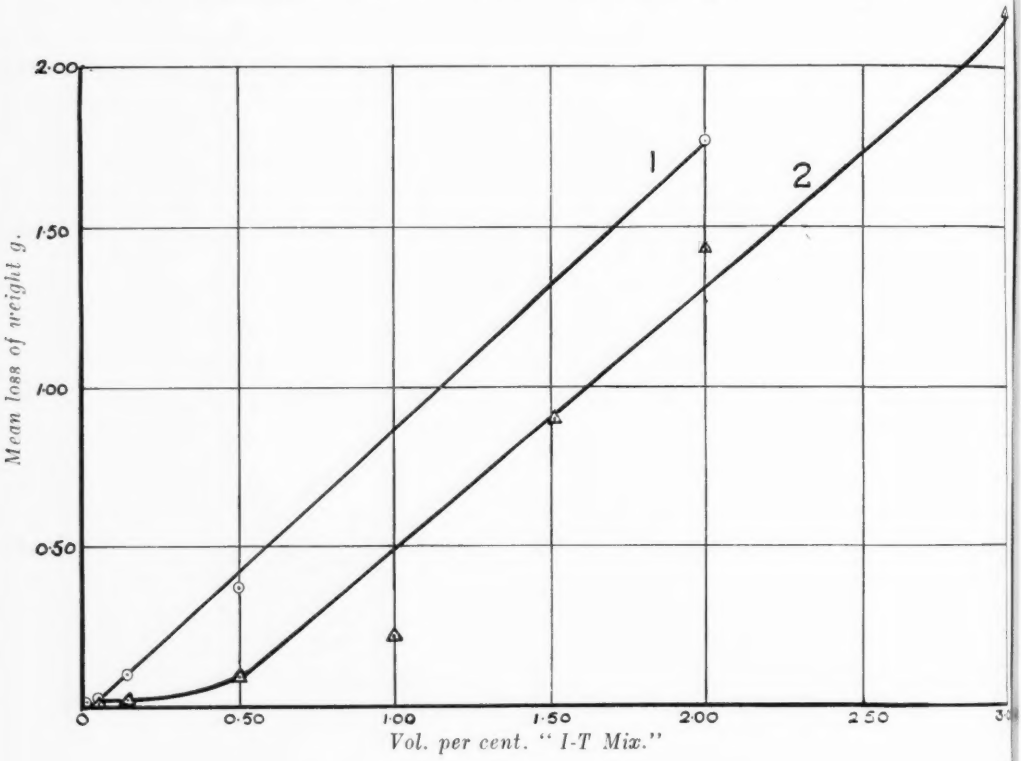

FIG. 2.

Per cent. " I-T Mix "/loss of weight curves.
1 : 6 weeks' exposure, 2 : 4 weeks' exposure.
Medium: 150 *ml. straight-run paraffin type aviation spirit* + 5*ml. water.*

hydroxide and gaseous hydrogen, the amount thus removed depending on the amount of " I-T Mix " present. The effect of increasing the time of exposure, therefore, will be to cause a greater increase of attack, in proportion to the attack after a short time, on specimens exposed to small lead contents than on those exposed to higher lead contents. The length of the straight line will tend, therefore, to increase as the time of exposure is increased. If the time of exposure were to be increased indefinitely, the amount of corrosion would probably be the same for all specimens, irrespective of the amount of " I-T Mix " present,

since it would depend finally only on the water content. The results are taken to justify the present procedure of acceleration tests.

Effect of Various Fuel Media

Loss of weight/time curves have been obtained with a 40 per cent. technical benzol mixture and a straight-run paraffin type aviation petrol. A large number of specimens were exposed simultaneously and at intervals of time up to 40 days

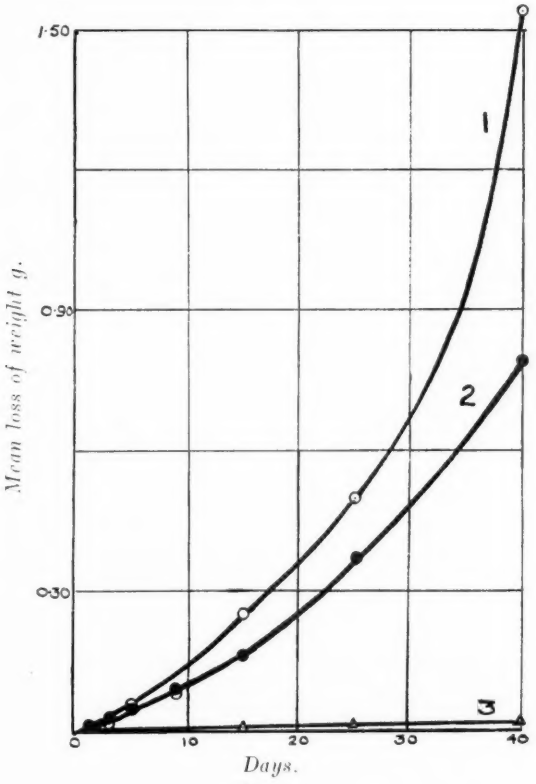

FIG. 3.

Time/corrosion curves in fuels + liquid water.

1. *Leaded straight-run spirit + water.*
2. *Leaded 40 per cent. technical benzol mixture + water.*
3. *Straight-run spirit + water only.*

duplicate specimens were removed, cleaned, and their losses of weight determined. In each vessel standard amounts of 3 ml. of " I-T Mix " and 5 ml. of water were added to the petrol. Fig. 3 shows the results, each point on the curves again representing the mean of duplicate experiments. In both fuels the rate of attack increased with time, but was considerably less after 40 days in the benzol mixture than after the same time in the straight-run fuel. The reason was thought to be due to the presence of sulphur compounds in the benzene which precipitated lead as sulphide. Lead and sulphide could be detected in the corro-

sion product. It was known that the benzene contained about 0.3 per cent. by weight of sulphur, mainly in the form of thiophene and carbon disulphide, whereas the paraffin base spirit contained approximately 0.015 per cent. by weight of sulphur mainly in the form of organic sulphides and disulphides.[4] A blended fuel made up with benzene free from sulphur compounds gave more attack than that given by the straight-run petrol or the ordinary benzol mixture, but when small amounts of carbon disulphide were added the attack was considerably reduced; thiophene had little effect. Some of these results are recorded in Table II.

A naphthenic type fuel to Air Ministry Specification D.T.D. 224, was also tested, but behaved similarly to the straight-run fuel and the results are, therefore, not shown.

In absence of "I-T Mix," petrol and free water (Fig. 3) caused only negligible attack on the alloy.

TABLE II.

EFFECT OF FUEL ON THE CORROSION OF ELEKTRON AM 503 IN PRESENCE OF WATER AND "I-T MIX."

Fuel.	Mean loss of weight of alloy, g. after 21 days' exposure.
Straight-run	0.45
40 per cent. benzol mixture containing S compounds ...	0.39
40 per cent. benzol mixture free from S compounds (1) ...	0.83
(1)+0.3 wt. per cent. CS_2	0.41
(1)+0.3 wt. per cent. thiophene	0.71

Effect of Liquid Water

Fig. 4 shows the results of experiments on the effects of increasing amounts of liquid water, up to 20 ml. per 150 ml. petrol, on the loss of weight of the alloy in mixtures containing fixed amounts of 3 ml. and 1 ml. of "I-T Mix," respectively. In both cases a maximum was obtained after which further increases in the amount of water caused a decrease in the total corrosion. An explanation is advanced later.

In absence of liquid water the leaded fuels investigated did not attack the alloy.

Effect of Separate Constituents of "I-T Mix"

Neither tetraethyl lead nor ethylene dibromide when separately dissolved in petrol, in presence of liquid water, cause serious attack of the alloy. When mixed and when liquid water is present, then serious corrosion takes place. Table III shows some loss of weight figures which support this statement and some typical specimens are illustrated in Figs. 5-7.

TABLE III.

EFFECT OF SEPARATE CONSTITUENTS OF "I-T MIX" ON LOSS OF WEIGHT OF AM 503. 150 ML. FUEL+5 ML. WATER USED. TIME OF EXPOSURE, SIX WEEKS.

Liquid used.	Losses of weight, g.
Straight-run + 2 ml. $PbEt_4$	0.15, 0.16
,, + 1 ml. $BrCH_2$-CH_2Br	0.05, 0.03
,, + 3 ml. "I-T Mix"	2.58, 2.73
Naphthenic spirit + 2 ml. $PbEt_4$	0.09, 0.08
,, ,, + 1 ml. $BrCH_2$-CH_2Br	0.03, 0.13
,, ,, + 3 ml. "I-T Mix"	2.60, 2.78

[4] Figures supplied by courtesy of the Anglo-Iranian Oil Co. Ltd.

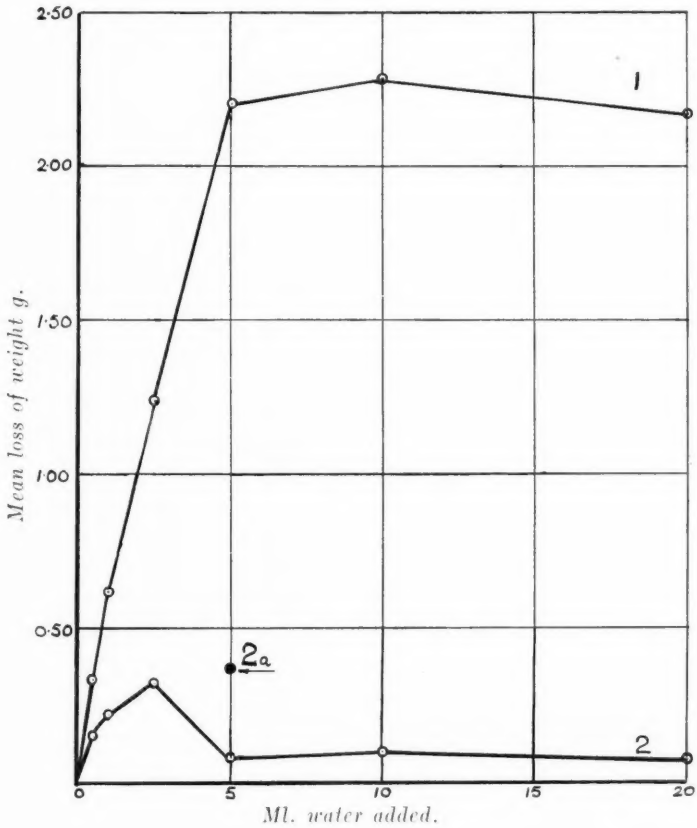

FIG. 4.

Effect of liquid water content on corrosion by leaded fuels.
1. 3 ml. "I-T Mix." 2. 1 ml. "I-T Mix."
2a. As 2, but metal surface "as received" (solitary point).

The effect of the blue dye used to colour the mixture, 1-4, ditoluidoanthraquinone (Royal Blue 90873) has been investigated by using mixtures of 150 ml. of straight-run paraffin type aviation spirit each containing 5 ml. water and 3 ml. of a mixture of two parts by volume of tetraethyl lead and one part by volume of ethylene dibromide, containing the dye in amounts varying from 0.005 per cent. to 0.34 per cent. by weight. The losses of weight of duplicate specimens exposed in these mixtures for two weeks are shown in Table IV.

TABLE IV.

EFFECT OF BLUE DYE IN "I-T MIX" ON CORROSION.

Dye added, weight per cent.	Losses of weight, g.
0.005	0.27, 0.32
0.021	0.32, 0.36
0.042	0.28, 0.40
0.085	0.30, 0.38
0.17	0.24, 0.41
0.34	0.16, 0.32

The results show that the dye has no definite effect on the amount of corrosion.

Mechanism of the Attack

The corrosion products were found to contain lead, and the effect of heating a mixture of tetraethyl lead, ethylene dibromide and water on a steam bath for several hours was, after cooling, the deposition of colourless needle-like crystals, which analysis showed to consist of lead bromide. A similar reaction cannot be assumed to occur at ordinary temperatures, therefore a mixture of 10 ml. of " I-T Mix " and 150 ml. distilled water were placed in one of the corrosion

FIG. 5.*
Petrol, water and tetraethyl lead.

FIG. 6.
Petrol, water and ethylene dibromide.

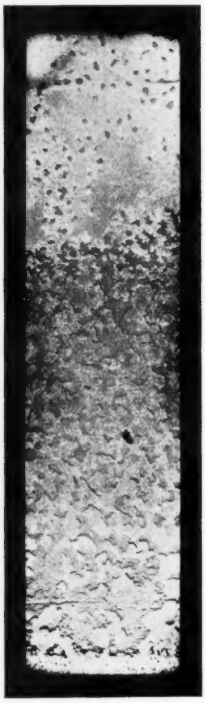

FIG. 7.*
Petrol, water and " I-T Mix."

* Corrosion product removed.

vessels and shaken for six weeks. The aqueous layer was then separated and taken to dryness by means of a draught of air from a fan. The residue consisted of a small quantity of colourless needle-like crystals, partly soluble in ether, and although there was not enough for quantitative examination, they were found to contain lead and bromine. A drop of the aqueous solution placed on a clean sheet of the Elektron alloy caused appreciable corrosion before evaporation of the water. A similar drop of distilled water left only a faint whitish ring. When the filtrate from a silver bromide precipitation was heated with sulphuric acid, traces of bromine were detected and thus indicate that the whole of the bromine

was not ionisable. It is probable, therefore, that the product contained not only lead bromide, but also compounds such as di and triethyl lead bromides described by Tafel[5] and by Grüttner and Krause.[6] These compounds are colourless solids, probably soluble in water, since diethyl lead dichloride is described as water-soluble,[6] and their aqueous solutions are probably slowly decomposed to form lead bromide. The solubility of lead bromide at 25° is 0.97 g. per 100 g. water, according to Lichty.[7]

It was considered, therefore, that in presence of tetraethyl lead and water, the ethylene dibromide is hydrolysed to hydrogen bromide and ethylene glycol.

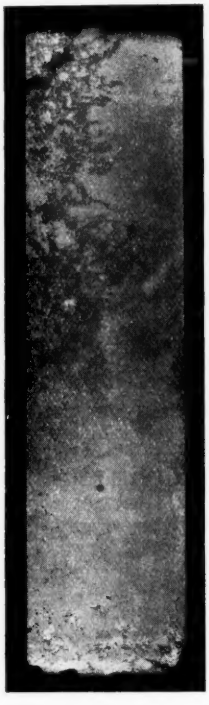

FIG. 8.*
Petrol, water and lead hydroxide.

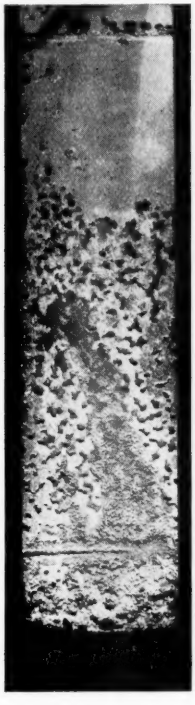

FIG. 9.*
Petrol, water, lead hydroxide and ethylene dibromide.

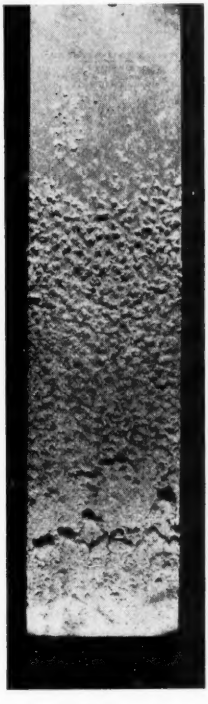

FIG. 10.
Petrol, water, tetraethyl lead and ethylene dibromide.
NOTE.—*Attack of similar type to Fig.* 9.

* Corrosion product removed.

Hydrogen bromide probably causes an accelerated hydrolysis of tetraethyl lead to form water soluble compounds containing lead and bromine.

As shown in Fig. 4, the effect of using the alloy surfaces " as received," *i.e.*, covered with a coating of magnesium carbonate and magnesium hydroxide, was to cause a considerably increased attack compared with that obtained from

[5] *Ber.* 1911, **44**, 336.
[6] *Ibid.* 1916, **49**, 1426.
[7] *J.A.C.S.*, 1903, **25**, 474.

a previously pickled surface. This was at first thought to be due to the alkaline surface layer catalysing the hydrolysis of tetraethyl lead, but experiments in which magnesium hydroxide and carbonate were added, as suspensions, to the aqueous layer, showed no increased attack. The explanation, therefore, is probably connected with the physical nature of the surface, which, being coarsely porous, can provide numerous points on which drops of water may cling.

In order to test whether small amounts of lead bromide, lead hydroxide and lead sulphide could cause increased attack of the alloy, in presence of the standard amounts of petrol and water (5 ml.) experiments were started in which these lead compounds were added in presence and in absence of added ethylene dibromide. The amounts used were equivalent to those which would have been formed by the total decomposition of the lead tetraethyl present in 3 ml. of " I-T Mix." The results of the experiments are shown in Table V, deep pitting being produced from lead hydroxide and lead bromide, attack being increased still more when ethylene dibromide was also present. Lead sulphide produced practically no attack, with or without the addition of ethylene dibromide, and this confirms the previously suggested explanation of the lower attack produced in benzol mixtures. It was found that lead hydroxide, in presence of ethylene dibromide and water, gave an attack of very similar type to that resulting from " I-T Mix," water and petrol mixtures (see Figs. 8-10). A similar attack was also produced by a mixture of magnesium bromide, water, petrol and lead tetraethyl, although separately both magnesium bromide and lead tetraethyl, with water and petrol, gave but little corrosion. Ethylene glycol, another product of hydrolysis of ethylene dibromide, was added to petrol, water and lead tetraethyl mixtures, and alloy specimens exposed thereto in order to test whether it was an active corrosion agent. The results are shown in Table VI and demonstrate the fact that ethylene glycol was not active in this respect.

The conclusion was drawn, therefore, that in presence of ethylene dibromide and water, lead tetraethyl is slowly hydrolysed, to form a mixture of lead hydroxide and lead bromide, together probably with some ethylated lead bromides. The aqueous layer can, therefore, react with the magnesium-base alloy to deposit lead, or a basic compound, *in a finely divided condition*, in which state it can probably act as low over-voltage cathodes. The formation of hydrogen bromide from the ethylene dibromide and water may still further increase corrosion by providing additional electrolyte. The presence of ethylene dibromide is certainly necessary, either to enhance the hydrolysis of tetraethyl lead or to provide additional electrolyte, or both, as shown by the experiments with tetraethyl lead, water and petrol only (Table IV). An explanation may now be advanced to account for the results shown in Fig. 4. Increasing amounts of liquid water must produce a continuously increasing dilution of the magnesium bromide formed

TABLE V.

EFFECT OF CERTAIN COMPOUNDS ON THE CORROSION OF AM 503 BY STRAIGHT-RUN AVIATION SPIRIT (150 ML.) AND WATER (5 ML.). TIME OF EXPOSURE, FOUR WEEKS.

Substance added.	Losses of weight, g.
0.889 g. PbS (1)	0.08, 0.13
(1)+1 ml. ethylene dibromide	0.16, 0.43
0.803 g. $PbO.Pb(OH)_2$ (2)	0.42, 0.54
(2)+1 ml. ethylene dibromide	1.20, 1.85
1.365 g. $PbBr_2$ (3)	0.45, 0.91
(3)+1 ml ethylene dibromide	0.67, 1.06
0.449 g. $MgBr_2$ 2 aq (4)	0.14, 0.22
(4)+2 ml. $PbEt_4$	1.94, 2.19
2 ml. $PbEt_4$	0.13, 0.14
3 ml. " I-T Mix "	0.95, 1.26

by hydrogen bromide, itself produced from the hydrolysis of the ethylene dibromide, and must finally reach a critical concentration with regard to stopping catalysis of the hydrolysis of tetraethyl lead. This critical amount of water will increase as the " I-T Mix " content increases, and further increase in the water content will then tend to result in a reduction of the total corrosion.

TABLE VI.

EFFECT OF ETHYLENE GLYCOL ON THE CORROSION OF AM 503 ALLOY BY STRAIGHT-RUN AVIATION SPIRIT (150 ML.) WATER (5 ML.) AND TETRAETHYL LEAD.
EXPOSURE, THREE WEEKS.

Substance added.	Losses of weight, g.
2 ml. $PbEt_4$ + 1 ml. $BrCH_2$-CH_2Br	2.20, 2.41
2 ml. $PbEt_4$	0.03, 0.04
2 ml. $PbEt_4$ + 1 ml. $OHCH_2$-CH_2OH	0.02, 0.05

Summary

The corrosion of Elektron Alloy AM 503 by leaded fuels has been investigated and the following points have been established:—

(1) Liquid water is necessary for the attack to proceed.

(2) The separate main constituents of " I-T Mix," *i.e.*, tetraethyl lead and ethylene dibromide, when mixed singly with petrol and water, do not cause appreciable corrosion, but intense attack may take place when they are mixed.

(3) Leaded technical benzol mixtures and water cause less attack than leaded straight-run paraffin type or naphthenic type aviation spirits and water.

(4) The blue dye usually employed in " I-T Mix " has no effect on corrosion.

(5) With fixed amounts of water the amount of corrosion is normally directly proportional to the amount of " I-T Mix " present.

(6) With fixed amounts of " I-T Mix " the amount of corrosion rises to a maximum and then tends to drop as the liquid water present in the fuel is increased.

The attack is probably caused by hydrolysis of the tetraethyl lead in presence of ethylene dibromide and water, to form water soluble salts such as lead bromide or ethylated lead bromides which deposit metallic lead on the alloy surface and provide low over-voltage cathodes.

The work has been carried out for the Corrosion Research Committee of the Department of Scientific and Industrial Research; thanks are due to the Chairman, Prof. Sir Harold Carpenter, F.R.S., and to Prof. G. T. Morgan, F.R.S., Director of Chemical Research, for permission to publish. Acknowledgment is due to the Anglo-Iranian Oil Company and to the Ethyl Export Corporation, who have kindly furnished supplies of aviation spirits, and tetraethyl lead and " I-T Mix " respectively.

Chemical Research Laboratory,
Teddington, Middlesex.

THE LIFT DISTRIBUTION ON A TWISTED ELLIPTIC WING, WITH SPECIAL REFERENCE TO THE EFFECT OF FLAPS

BY

J. LOCKWOOD TAYLOR, D.Sc., A.M.I.N.A.

Problems involving discontinuous aerodynamic twist, as for a flapped wing, are not readily soluble for wings having a rectangular plan form or straight taper. Lotz's method (*R.Ae.S. Journal*, May, 1934) has been stated to be particularly suitable, but a recent American report used in preference a direct method of successive approximation. In either case a fair amount of labour is involved, and the final results are only approximate. The exact solution for a wing of elliptic plan form, whilst not directly applicable to the usual type of tapered monoplane wing, is readily obtainable, and should give a good idea of the lift distribution and induced drag due to a flap on an actual wing.

General Solution for the Twisted Elliptic Wing

With the usual notation, the general equation to determine the circulation

$$K = 4sV \sum_{1}^{\infty} A_n \sin n\theta$$

and hence the lift distribution ρVK, of a monoplane wing, by Glauert's method, is

$$\sum_{1} A_n \sin n\theta \,(n\mu + \sin\theta) = \mu\alpha \sin\theta.$$

For an elliptic wing, putting

$$\mu = a_0 c/4s = (a_0 c_0/4s)\sin\theta,$$

this becomes

$$\sum A_n \sin n\theta \,(n\mu_0 + 1) = \mu_0 \alpha \sin\theta$$

where μ_0 is written for $a_0 c_0/4s$.

To solve for A_n, it is only necessary to expand $\alpha \sin\theta$ in a Fourier series, giving,

$$A_n = (2/\pi)\int_0^{\pi} \alpha \sin\theta \sin n\theta d\theta \times \{\mu_0/(n\mu_0 + 1)\}.$$

The induced drag coefficient is given, as usual, by

$$k_{D_i} = (S/2\pi s^2)(1+\delta)k_L^2$$

where

$$(1+\delta) = \sum n A_n^2/A_1^2.$$

A_1, which determines the total lift, contains the factor $1/(\mu_0 + 1)$, which is the ratio of the actual lift to the lift uncorrected for downwash, and this is the same whether the incidence is uniform or not.

Flapped Elliptic Wing

The lift due to the flap, at any point of the span, is additional to that of the normal wing, at any angle of incidence, and it is convenient to consider it separately. Aerodynamically, the effect of a flap whose chord is a constant proportion of the wing chord is a change in the incidence, measured from no-lift,

for the flapped portion of the span. If the flap extends over a proportion of the total span equal to $\cos\theta_0$, and produces a change in the local no-lift angle of amount β (radians), the value of the coefficients A_n is got by putting $\alpha=\beta$ from $\theta=\theta_0$ to $(\pi-\theta_0)$.

Integration gives

$$A_n=(2\beta/\pi)\{\mu_0/(n\mu_0+1)\}\int_{\theta_0}^{\pi-\theta_0}\sin\theta\sin n\theta d\theta$$

$$=(2\beta/\pi)\{\mu_0/(n\mu_0+1)\}[(\sin\overline{n-1}\theta)/2(n-1)-(\sin\overline{n+1}\theta)/2(n+1)]_{\theta_0}^{\pi-\theta_0}$$

$$=(2\beta/\pi)\{\mu_0/(n\mu_0+1)\}[(\sin\overline{n+1}\theta_0)/(n+1)-(\sin\overline{n-1}\theta_0)/(n-1)]$$

where only the odd values of n are to be taken, and for the special case $n=1$, the second term in brackets is to be replaced by $(\pi/2-\theta_0)$.

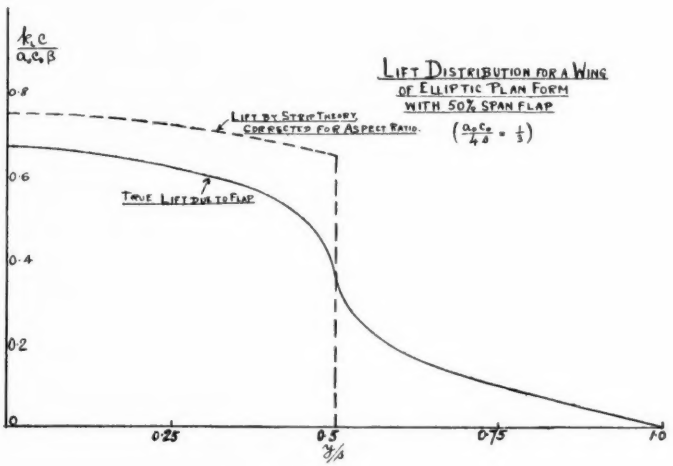

FIG. 1

This gives the distribution over the span of the lift due to the flap, namely, $k_L c=4s\,\Sigma A_n\sin n\theta$, which is plotted in Fig. 1 for the particular case of a 50 per cent. span flap ($\theta_0=60°$). The dotted curve shows the " strip theory " lift corrected for aspect ratio only. In accordance with the remark above as to the value of A_1, which determines the total lift, this is exactly proportional to the flapped area. Accordingly, the areas of the dotted curve and the true lift distribution curve are identical.

The increase in induced drag coefficient due to the flap is $(S/2\pi s^2)\,\delta k_L^2$ where

$$\delta=\sum_1^\infty(nA_n^2/A_1^2)-1 \text{ or } \sum_3^\infty(nA_n^2/A_1^2).$$

Since

$$k_L=(2\pi s^2/S)\,A_1$$

$$(S/2\pi s^2)\,\delta k_L^2=(2\pi s^2/S)\sum_3^\infty nA_n^2.$$

It is noted that this is independent of A_1; in other words, the increase in induced drag is independent of lift, and is not very well expressed by the usual correction factor $(1+\delta)$, since δ will vary with the lift coefficient.

Some numerical values for the increase in induced drag coefficient due to the flap are as follows:—

Flap span	26%	50%	71%
Increase in k_{Di} ...	$0.10\,\beta^2$	$0.165\,\beta^2$	$0.10\,\beta^2$

These apply to a flap extending over the central part of the wing. For flaps over the outer part of the wing the increase is the same at the corresponding flap span, *e.g.*, a 26 per cent. central flap corresponds with 74 per cent. tip flaps.

It is noted that the increase in induced drag is quite moderate. A flap producing a change in local no-lift angle of 0.2 radians, a fairly extreme figure, only gives an increase in induced drag of 0.0066, when covering 50 per cent. of the span. An increase of this amount is likely to be masked by the high profile drag in wind tunnel tests of ordinary high drag flaps.

NOTATION.

K = circulation constant.
s = semi-span; S wing area.
V = air speed.
y = distance along semi-span ($y/s = \cos\theta$).
ρ = density of air.
$\mu = a_0 c/4s$.
$\mu_0 = a_0 c_0/4s$.
α = angle of incidence.
β = change in local no-lift angle due to flap.

In the numerical work μ_0 is taken as $\frac{1}{3}$, corresponding with an aspect ratio ($4s^2/S$) of approximately 6.

SUMMARY OF THE SOCIETY'S ACTIVITIES

DECEMBER, 1934—DECEMBER, 1935

The following places on permanent record in the Journal the notices which have appeared in the Monthly Notices inset in the Journal and so summarises the activities of the Society for the year. Activities not reported in the Summary will be given in the Annual Report of the Council which will be published in the Journal for March, 1936.

Council and Officers, 1935-36

President:

Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.I.Ae.E., M.P.

Past-President:

Mr. C. R. Fairey, M.B.E., F.R.Ae.S.

Vice-Presidents:

Mr. H. E. Wimperis, C.B., C.B.E., M.A., M.I.E.E., F.R.Ae.S.
Major T. M. Barlow, M.Sc. (Eng.), M.Inst.C.E., M.I.Mech.E., F.R.Ae.S.

Council:

Captain P. D. Acland.
Major T. M. Barlow, M.Sc. (Eng.), M.Inst.C.E., M.I.Mech.E., F.R.Ae.S.
Major J. S. Buchanan, C.B.E., A.M.I.Mech.E., F.R.Ae.S.
Major G. P. Bulman, O.B.E., B.Sc., F.R.Ae.S.
Mr. R. S. Capon, O.B.E., B.A., F.R.Ae.S.
Mr. H. Roxbee Cox, Ph.D., D.I.C., B.Sc., A.F.R.Ae.S.
Mr. E. C. Gordon England, F.R.Ae.S.
Mr. S. Scott-Hall, A.C.G.I., M.Sc., D.I.C., A.F.R.Ae.S.
Professor F. T. Hill, F.R.Ae.S., M.I.Ae.E.
Professor G. T. R. Hill, M.C., M.Sc., F.R.Ae.S.
Captain A. G. Lamplugh, F.R.Ae.S., M.I.Ae.E., M.I.Mech.E., F.R.G.S.
Mr. W. O. Manning, F.R.Ae.S.
Major R. H. Mayo, O.B.E., M.A., Assoc.M.Inst.C.E., F.R.Ae.S.
Dr. N. A. V. Piercy, M.I.Mech.E., Assoc.M.Inst.C.E., F.R.Ae.S.
Mr. D. R. Pye, M.A., M.I.Mech.E., F.R.Ae.S.
Mr. E. F. Relf, A.R.C.Sc., F.R.Ae.S.
Mr. W. P. Savage, A.M.I.Aut.E., A.F.R.Ae.S.
Mr. O. E. Simmonds, M.A., F.R.Ae.S., M.I.Ae.E., M.P.
Mr. H. E. Wimperis, C.B., C.B.E., M.A., M.I.E.E., F.R.Ae.S.

Hon. Treasurer:

Major D. H. Kennedy, O.B.E., F.R.Ae.S.

Solicitor:

Mr. Lawrence A. Wingfield, M.C., D.F.C., A.R.Ae.S.I.

Hon. Librarian:
Mr. J. E. Hodgson, Hon. F.R.Ae.S.

Hon. Accountant:
Mr. A. N. D. Smith, F.C.A.

Secretary and Editor:
Captain J. Laurence Pritchard, Hon. F.R.Ae.S., M.I.Ae.S.

Committees of Council

The following Committees of Council were appointed for 1935-36:—

Grading Committee:

Captain F. S. Barnwell, Mr. R. A. Bruce, Major G. P. Bulman, Major F. A. Bumpus, Mr. W. S. Farren, Lieut.-Col. L. F. R. Fell, Mr. A. Gouge, Prof. F. T. Hill, Mr. R. J. Mitchell, Mr. W. P. Savage, Lord Sempill, Prof. R. V. Southwell and Dr. H. C. Watts.

Finance Committee:

Captain P. D. Acland, Mr. Griffith Brewer, Mr. E. C. Gordon England, Mr. C. R. Fairey, Professor F. T. Hill, Mr. J. E. Hodgson (Honorary Librarian), Major D. H. Kennedy (Honorary Treasurer), Captain A. G. Lamplugh, Mr. John Lord, Mr. F. R. Simms, Mr. A. N. D. Smith (Honorary Accountant) and Mr. L. A. Wingfield (Solicitor).

Lectures Committee:

Major R. H. Mayo (Chairman), Major G. P. Bulman, Mr. R. S. Capon, Mr. M. Langley, Mr. W. O. Manning, Mr. D. R. Pye, Mr. S. Scott-Hall, Mr. C. C. Walker.

Educations and Examinations Committee:

Major T. M. Barlow (Chairman), Mr. H. Roxbee-Cox, Mr. S. H. Evans, Professor F. T. Hill, Mr. M. Langley, Mr. W. M. Page, Dr. N. A. V. Piercy, Mr. W. P. Savage.

Rules Sub-Committee:

Professor L. Bairstow, Mr. Griffith Brewer, Mr. A. H. Hall, Major D. H. Kennedy (Honorary Treasurer), Mr. W. O. Manning, Lord Sempill, Mr. L. A. Wingfield (Solicitor).

Medals and Awards Committee:

Mr. H. E. Wimperis (Chairman), Mr. Griffith Brewer, Sir Robert Brooke-Popham, Major J. S. Buchanan, Mr. A. H. R. Fedden, Group Captain G. B. Hynes, Mr. W. O. Manning, Sir A. Verdon-Roe, Mr. G. R. Volkert, Mr. C. C. Walker, Mr. L. A. Wingfield (Solicitor) and Mr. R. McKinnon Wood.

Amulree Committee:

Lord Amulree, Prof. L. Bairstow, Mr. Griffith Brewer, Mr. C. R. Fairey, Lord Gorell, Major D. H. Kennedy, Lord Mottistone, Lord Sempill and Mr. H. E. Wimperis.

REPRESENTATIVES ON OTHER BODIES.

Advisory Council of the Science Museum: Lord Sempill.

Air League of the British Empire: Mr. W. O. Manning and Mr. Griffith Brewer.

Association of Special Libraries and Information Bureaux: Mr. J. E. Hodgson (Hon. Librarian).

British Corporation Register of Shipping and Aircraft, Aviation Committee: Lord Sempill.

British Gliding Association: Council: **Mr. W. O. Manning.**
Technical Committee: Captain J. L. Pritchard, Professor F. T. Hill.

British Standards Institution Aircraft Committee: **Major R. H. Mayo and Dr. H. C. Watts.**

British Standards Institution, Committee on Symbols and Abbreviations used in Engineering: Major A. R. Low.

Engineering Joint Council: Mr. C. R. Fairey, M.B.E., F.R.Ae.S.
(*Special Educational Representative*): Major T. M. Barlow.

Joint Standing Committee with the Society of British Aircraft Constructors and the Royal Aero Club:
Professor L. Bairstow, Lord Sempill, Lieut.-Col. J. T. C. Moore-Brabazon.

Lloyds Aviation Committee: Lieut.-Col. J. T. C. Moore-Brabazon.

National Central Library: **Mr. J. E. Hodgson (Hon. Librarian).**

Seagrave Memorial Fund Committee: **Mr. C. R. Fairey.**

Students' Section: Mr. H. Leaderman (Honorary Secretary).

Annual General Meeting

The Annual General Meeting of the Society was held on Tuesday, March 26th, 1935, at 6.30 p.m., in the Library at 7, Albemarle Street, W.1.

Present:

Lieut.-Col. J. T. C. Moore-Brabazon (President) in the chair.

Captain P. D. Acland (Companion).
R. M. Alcock (Associate Fellow).
Major J. W. Allsop (Associate Fellow).
A. E. Bingham (Associate Member).
Major G. P. Bulman (Fellow).
J. D. Campbell (Associate Fellow).
Michael A. Doyle (Associate Fellow).
K. W. Chapman (Student).
S. H. Evans (Member and Associate Fellow).
W. E. Gray (Companion).
S. Scott-Hall (Associate Fellow).
Prof. F. T. Hill (Fellow and Member).
Major D. H. Kennedy (Fellow) (Hon. Treasurer).
M. Langley (Member).
J. W. Maccoll (Associate Fellow).
W. O. Manning (Fellow).
P. R. Nazir (Associate Fellow).
Major W. P. Savage (Associate Fellow).
Lieut.-Commander the Hon. J. M. Southwell (Associate Fellow).
H. Sims-White (Associate).
H. E. Wimperis (Fellow).
L. A. Wingfield (Associate) (Solicitor).

Captain J. Laurence Pritchard (Secretary).

1. The President read the notice convening the meeting.

2. The following were appointed Scrutineers of the Ballot for the vacancies on the Council:—

Mr. W. O. Manning.
Mr. S. Scott-Hall.
Lieut.-Cmdr. the Hon. J. M. Southwell.

3. The President thanked the honorary officials, Major D. H. Kennedy (Honorary Treasurer), Mr. J. E. Hodgson (Honorary Librarian), Mr. A. N. D.

Smith (Honorary Accountant) and Mr. L. A. Wingfield (Solicitor) for their services during the year. He also referred to the work of the Secretary and said he thought all members would join him in appreciation of that work.

The President said he would very much like to thank those members who had delivered lectures to schools during the year. It was a very fine part of the Society's work and he hoped it would increase in the future.

He drew the attention of members to the fact that the membership now totalled 1,500 for the first time and he thought they would agree that it was a remarkable figure.

The President said he would like to mention here that the Wilbur Wright Lecture this year would be given on May 31st or July 12th and members would be informed as soon as the date was definitely fixed. He also drew attention to the Garden Party to be held on May 5th at Mr. Fairey's aerodrome, when some new aircraft would be on show.

He thought members would be interested to hear of a proposed new building, "Air House." The trade appeared likely to rally round and join in the scheme, so that it appeared possible to build a central house. The idea was to have a building large enough for the requirements of the Royal Aeronautical Society with lecture hall and one which would house other aeronautical bodies and firms. The project looked most hopeful.

The President then invited members to raise any questions they cared to on the Society's work, policy and future activities.

Mr. WINGFIELD: There was one point which puzzled him in the Accounts and that was how a loss on Investments could be called a loss of Income at all, and he thought it should be a loss on Capital Account.

Major KENNEDY: The loss arose through the compulsory sale of Bonds. It was a question of policy whether a profit or loss on Investments should go to Capital Account.

Mr. W. E. GRAY said he would like to see a little more time allowed for discussions after lectures.

The PRESIDENT: He rather felt responsible for the cutting down of the time for discussions as he thought two hours were long enough for a lecture.

Mr. S. H. EVANS: The real trouble with the lectures was that the discussions were not thrown open. The same people were called upon to speak time after time.

Mr. M. LANGLEY: There is a method in operation by other societies where the papers were published in the Journal beforehand and the meetings were open for discussion only.

The PRESIDENT: The papers might be limited to half an hour.

Mr. S. H. EVANS: He thought 45 minutes was more suitable.

The PRESIDENT: It was up to those who wanted to speak at the lectures to let the Secretary know.

Mr. WIMPERIS: There is some time wasted waiting for people to get up and speak when the discussion was thrown open.

Mr. J. D. CAMPBELL: Members could always apply for advance proofs of the papers and so come prepared to take part in the discussions.

Major KENNEDY: He suggested having slips of paper at the entrance for people to write their names on indicating their desire to take part in the discussion.

The PRESIDENT: He thought that a sound idea and would have slips ready for members at the next lecture.

Mr. WIMPERIS: The times of starting the lectures were inconvenient.

Mr. J. D. CAMPBELL: He suggested continuing the discussions on papers where necessary as in the case of "The Training of Aeronautical Engineers."

Mr. S. H. EVANS: The trouble with a continued discussion was that the right people did not turn up to them.

The PRESIDENT: In future he would limit the reading of the paper to 45 minutes and limit each speaker to five minutes. Members wishing to speak should send their names to him on the slip of paper provided.

Mr. A. E. BINGHAM: Other societies issued their advance proofs free and it would be a good thing if the Society did likewise.

The SECRETARY: Only a nominal charge was made which did not cover the cost of printing. The Institution of Automobile Engineers charge 1s. 6d. per copy at their joint lectures.

Mr. LANGLEY: He noticed that a firm of publishers had advertised on the last page of one advance proof.

The SECRETARY: This was an attempt to keep down the cost, but it was not found successful.

Major KENNEDY: A great number of visitors attended the lectures who did not contribute to the funds of the Society in any way and the small charge for the advance proof in their case was justified.

The SECRETARY: People interested were circularised before each lecture and are asked to return postcards indicating their intention to attend the lecture when advance proofs are sent to them free.

Mr. S. H. EVANS: Was anything more being done about the training of aeronautical engineers arising out of the discussion on the subject? He quoted a case of a man being trained at one of the aeronautical engineering colleges and not being fit for a post in the industry. He was also surprised at correspondence course schools stating on their syllabi that they coached for the Associate Fellowship and Associate Membership Examinations. In the case of the Society's examinations, practically all they consisted of were fundamental principles.

Mr. M. LANGLEY: There was perhaps work to be done on that point by the Examinations Committee.

Mr. M. DOYLE: They were bound to get people who were good at examinations and no good in an actual job.

Mr. EVANS: He thought it would be a good thing to obtain statistics as to the number of draughtsmen employed by aircraft firms who were Associate Fellows of the Society. He was surprised that in his experience there were so few. He thought the Associate Membership was a lower grade than the Associate Fellowship.

Mr. LANGLEY: He corrected Mr. Evans on a point of order and stated that the two grades were equal. He thought though there was a lot in what Mr. Evans said and he suggested the S.B.A.C. should be asked to get out statistics.

Mr. EVANS: Very often one could get a really good practical man who had no examination qualifications in by writing and recommending him and he thought this should be more widely accepted.

The SECRETARY: What substitute for a degree could Mr. Evans suggest?

Mr. EVANS: It was the Society's examination he disagreed with.

The SECRETARY: There were exemptions such as the Higher National Diploma or Certificate.

The PRESIDENT, summing up, said what appears to be wanted is more latitude in the recommendation of candidates.

Mr. EVANS: His objection to the Society's examination was that it was a very academic one.

The PRESIDENT: This is a scientific and technical Society and it would always be difficult to weld them together. He suggested to Mr. Evans that it would be a very good thing if he joined the Examinations Committee, and Mr. Evans consented to do so.

Mr. SIMS-WHITE: Referring to the remarks made about the correspondence school courses coaching for the Society's examination, he said surely they could only be expected to cater for the theoretical side and that practical training should be available at works.

The PRESIDENT: He was sure no attack was intended on the correspondence courses. It was the Society's examinations that were being criticised.

4. Captain P. D. Acland proposed that the Auditors, Messrs. Price, Waterhouse be re-elected for the ensuing year, seconded by Mr. M. Langley and carried unanimously.

The President then read the report of the Scrutineers resulting in the election of the following candidates, with their proposers and supporters:—

Name.	Grade in Society, etc.	Proposer.	Seconders.
P. D. Acland ...	Companion ...	J. T. C. Moore-Brabazon ...	J. S. Buchanan A. H. R. Fedden
T. M. Barlow ...	Fellow	C. F. Hodgson ...	A. C. Barlow A. C. Brown
J. S. Buchanan	Fellow	D. R. Pye ...	H. E. Wimperis C. J. Stewart
G. P. Bulman ...	Fellow	A. H. R. Fedden	F. B. Halford A. J. Rowledge
H. Roxbee-Cox...	Associate Fellow	F. T. Hill ...	A. J. Sutton Pippard S. C. Redshaw
G. T. R. Hill ...	Fellow	H. E. Wimperis	D. R. Pye J. S. Buchanan
A. G. Lamplugh	Fellow & Member	F. C. Shelmerdine	C. C. Walker R. H. Mayo
R. H. Mayo ...	Fellow	J. S. Buchanan...	A. G. Lamplugh Griffith Brewer
N. A. V. Piercy	Fellow	J. T. C. Moore-Brabazon ...	L. Bairstow W. Lockwood Marsh
O. E. Simmonds	Fellow & Member	J. T. C. Moore-Brabazon ...	C. R. Fairey P. D. Acland

A vote of thanks to the Scrutineers was proposed by the President, seconded by Mr. W. E. Gray.

A Special General Meeting was held on Tuesday, March 26th, 1935, in the Library at 7, Albemarle Street, following the Annual General Meeting.

Present:

Lieut.-Col. J. T. C. Moore-Brabazon (President) in the chair.

Captain P. D. Acland (Companion).
R. M. Alcock (Associate Fellow).
Major J. W. Allsop (Associate Fellow).
A. E. Bingham (Associate Member).
Major G. P. Bulman (Fellow).
J. D. Campbell (Associate Fellow).
Michael A. Doyle (Associate Fellow).
K. W. Chapman (Student).
S. H. Evans (Member and Associate Fellow).
W. E. Gray (Companion).
S. Scott-Hall (Associate Fellow).
Prof. F. T. Hill (Fellow and Member).
Major D. H. Kennedy (Fellow) (Hon. Treasurer).
M. Langley (Member).
J. W. Maccoll (Associate Fellow).
W. O. Manning (Fellow).
P. R. Nazir (Associate Fellow).
Major W. P. Savage (Assoc. Fellow).
Lieut.-Commander the Hon. J. M. Southwell (Associate Fellow).
H. Sims-White (Associate).
H. E. Wimperis (Fellow) (Vice-President).
L. A. Wingfield (Associate) (Solicitor).

Captain J. Laurence Pritchard (Secretary).

1. The President explained the purpose for which the Special General Meeting had been called, that of passing the amended Rules as circulated to

members on the notice calling the meeting. The President reminded those present that the amendments were suggested as meeting with the requirements of the resolution passed at the last Annual General Meeting as follows:—

> " That this Annual General Meeting draws the attention of the Council to the absence in the Rules of any regulations laying down precisely the procedure which should be adopted in the event of a change in the Rules being proposed; and requests the Council to consider the matter, and to submit proposals to the next Annual General Meeting or to a Special General Meeting."

The adoption of the amendments were proposed by Mr. H. E. Wimperis and seconded by Mr. M. Langley. The alterations in the Rules were carried unanimously.

The alterations are as follows:—

RULE 105.

That a full stop should be placed after the words " for the ensuing year," that the words " and to consider any other business of which proper notice has been given in calling the meeting " be deleted and the words " Special business may only be considered at a Special General Meeting " be added.

RULE 108A.

The Council put forward the proposal that a new Rule should be added between the present Rules 108 and 109 to read as follows:—

> " Not less than fourteen clear days' notice shall be given of any Annual General Meeting or Special General Meeting, and the notice convening the meeting shall state the nature of the business to be transacted, and in the case of a Special General Meeting shall set out the resolutions to be considered thereat."

RULE 111.

The Council propose that the following shall be added to the present Rule:—

> " Where any special resolution intended to make a change in these Rules is proposed at a Special General Meeting and an amendment to such resolution is proposed, seconded and carried by a two-thirds majority of those present, the Chairman of the meeting shall call for a postal vote.
>
> " An entry in the Minutes by the Chairman on the result of a voting by a show of hands shall be conclusive evidence thereon."

Election of President

Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.I.Ae.E., M.P., was unanimously elected President of the Society for a second year of office for the year 1935-1936, at the Council Meeting held on May 14th, 1935.

Election of Vice-Presidents

The following were elected Vice-Presidents of the Society for the year 1935-1936, at the Council Meeting held on May 14th, 1935:—

Mr. H. E. Wimperis, C.B.E., F.R.Ae.S.

Major T. M. Barlow, M.Sc.(Eng.), M.Inst.C.E., M.I.Mech.E., F.R.Ae.S.

New Year Honours

Order of the Indian Empire (C.I.E.):—

F. Tymms, Esq., M.C., *Fellow of the Society.*

King's Birthday Honours

G.C.B. (Military Division):—

Air Chief Marshal Sir Edward Leonard Ellington, K.C.B., C.M.G., C.B.E., *Associate Fellow.*

K.C.B. (Military Division):—

Air Marshal Arthur Murray Longmore, C.B., D.S.O., *Founder Member.*

C.B. (Civil Division):—

Harry Egerton Wimperis, C.B.E., M.A., M.I.E.E., *Vice-President, Member of Council* and *Fellow.*

Elections

On December 11th, 1934:—

Associate Fellows.—Henry Bailey, Thomas William Clavell, Wallace William Greenfield, John Alexander Christie Manson.

Associates.—Arthur Frank Oliver, Keith Langford Smith, Miss Dorothy Spicer, Edwin Sidney Street.

Students.—Eric John Andrews, Jan Eduard Breyer, Charles Gordon Clegg, Andrew William Henry Dalrymple, Harry James Evans, Kirpal Singh Goolry, Glencairn Sholto Ogilvie, Kenneth Cecil Pratt, Robert Scott, John Philip Smith, Luis Ricardo Vigil, Thomas Percy Wheeler.

Companion.—Henry Burton Tate.

On January 8th, 1935:—

Associate Fellows.—Richard Meredith Alcock, Jack Glover, Harold Cecil Smith, Herbert William Victor Steventon, Norman Sykes, Frederick William Westley, Will Walter White.

Associate Members.—Percy William Nunn, Charles Henry Sparkes.

Associates.—Edward Dunham Hall, Sydney Walter Slaughter.

Students.—Ronald Merriman Barry, Alan Coatsworth Brown, Carl Robert Chronander, John Hunter Coghlan, Francis William Fielding, Herbert Fillingham, Ronald Ogilvy Maurice Graham, Frank Jefferson Horn, Shiv Parkash Kathuria, Edward Peter Maynard Keeling, Walter Frederick Locke, Patrick Peek Robertson.

Companion.—Vicomte de Sibour.

On February 12th, 1935:—

Fellows.—Charles Dempster Breese (from Associate Fellow), Henry Nigel St. Valery Norman (from Associate Fellow).

Associate Fellows.—Richard Meredith Alcock, Kenneth Lenton Boswell, Arnold Cadman Clinton, John Wesley Loader, James Murray, Ivor Jones Rees, Hormusji Motashaw Wadia.

Associate Member.—Cecil Herbert Lucas.

Associates.—Robert Edmond Godefroy Brittain, Robert Charles Cox, Roderick Herbert Barrington Grattan, Lawrence Pilkington Hirsh, Graham Stobart Hook, Horace Charles Luttman, Frank Marsh.

Students.—William Kenneth Chapman, Nicholas Gresham Cooke, James A. Currie, William John Goodey, Denis Simpson Gunning, Dennis Malcolm George Harper, Andrew Keith Hunter, David Mellor Jamieson, Jack Voyna Leslie Kemp, Herbert Leaderman, Edward Loveless, Lawrence Richard Morphew, Norman Francis Newberry, Dennis Ralph Sherwin, John Alfred Sizer, Humphrey Montague Smith, Peter Joseph John Weiss, Philip Gordon Wright, Frederick Thomas Young.

On March 12th, 1935:—

Associate Fellows.—Ernest Leon Bass, Erico Charles Nicola, John Arthur Parkinson Nidd, Ralph Poole.

Associate Member.—George Reginald Clary.

Associates.—Henry Dixon Arnott (Australian), Frederick Alfred Kent, Hedley Lionel Mauler.

Students.—Lionel Hubert Charles Cranfield, Ian G. Duncan, Charles Peter Graham Engelbach, Attwood James Hobbs, Ian George Hopkinson, Miles Craven Rigby, Alexander Reginald Ward, David Wark.

Companion.—Robert Dudley Morrison.

On April 9th, 1935:—

Fellow.—Alan Theodore Eden Eadon.

Associate Fellows.—Jack Lobley, John Howard Sucksmith.

Associate Members.—S. T. Carpenter, David William Stannard.

Associates.—Dermot Mitchell Egan, George William Wilson.

Students.—Francis Joseph Buller, Peter Nisbet Cunningham, Harold Raymond Footit, Douglas Favel Horne, Alastair Rennoldson Ross, George Peter Hutton Square, Cedric Arthur Cuthbert Stone, Rowland Towers, Charles Lewis Wright.

Companions.—Richard Derwick Winsloe, Roy O'Donnell, John S. Gibbons and Thomas P. Mills.

On May 14th, 1935:—

Associate Fellows.—Herbert Harry Knight, Hervey Pugh Speake.

Associate Members.—Esmond Allen Gibson, Jack Gurney, Raj Nath Kathju, Stanley Spencer, Hubert Courtney Witts.

Associate.—Bimal Kumar Basu.

Student.—Stuart Claude Etheridge Braund.

Companions.—Baron Von Haersolte, Eric Winthrop Woodruff.

On June 18th, 1935:—

Member.—Arthur William Murphy (from Associate Member).

Associate Fellows.—Donald Raymond Price Amor, Charles Herbert Colvin, Harold Everett Falkner, William Garrow-Fisher (from Companion), Geert Otten, Robert Talbot Youngman.

Associate Members.—Edward Dixie Keen (from Associate), Raymond Harcourt Woodall.

Associates.—Gurbax Singh Chowdhery, Albert Godfrey Gooch (from Student), Ronald Douglas King.

Students.—Clifford Claude Caple, Ian Bowman Fleming, Miss Grace Mary Bruce Quennell, John Anthony Mawson Reid, Stephen Arthur Wathen Thompson, John Powell Walters.

Companion.—Gerald Alexander Fraser Embleton.

On September 10th, 1935:—

Fellows.—Hugh Burroughes, Jean Pontremoli.

Associate Fellows.—R. P. Alston, H. C. W. Brewer, W. E. W. Petter, H. W. Sims-White, J. E. Walker, G. H. C. Willins.

Associates.—M. W. Bartlett, S. Bhandari, R. Denton-Samuel, R. Douglas, M. L. Gaine, J. M. Grennen, K. J. Sewell, G. A. Stenning, W. P. Lewis.

Students.—E. E. Blofield, A. H. Emden, W. I. Foster, H. G. Grigg, A. R. B. Nash, F. H. Robertson.

Companions.—J. R. Crean, V. L. Gruberg, N. Irmescu, E. W. C. Wilkins.

On October 8th, 1935:—

Fellow.—Francis Claude Shelmerdine (from Associate Fellow).

Associate Fellows.—Thomas Stanley Harker (from Student), Gustavus McAlpine, Richard Babington Winn.

Associate Members.—Harold Horace Bertram Lewis, Sures Chandra Sen (also Associate Fellow), Willows Septimus Shaw (from Associate), George Frederick Strand.

Associates.—Frederick Beach (from Student), Robert Dudley Morrison (from Companion), Ronald Windle Potts, Reginald George Robertson.

Students.—Sydney Joseph Cox, Henry Aldyn Craw, Edward Reginald Davidson, Robert Terence Elmes, Harry Gonnell Fox, Edwin William John Gray, Vernon Arthur Moore Hunt, Alexander Myles Jardine, Tek Send Li, Harold George Litchfield, Edward Ogden, Ronald Maitland Austin Rice, Reginald William Macer Sennitt.

On November 12th, 1935:—

Associate Fellows.—John Allen Rowlatt Jones, David Richmond Hay Surgeoner.

Associates.—Ronald Eric Bishop, Philip Alexander Roby Bremridge, John Martin Freeman, Reginald Frederick Long, Donald McCorquodale, Murzban Ruttonjee Mandviwalla, Maurice Robert Desmond Trewby.

Students.—John White Burman, Leslie Gordon Byrne, Norman Coles, Gerald Claud Crack, John Horace Hamilton Davison, James Charles Floyd, Stanley John Gower French, Thomas Edward Goligher, Ruben Hadekel, Denis Alban James Harben, Leslie Ronald Hordley King, Edward William Lofts, Lionel Pekarksy, Charles Peter Plantin, Wynand Johannes Pretorius, D. W. Burnett Rae, William George Savory, Maurice Sydney Spickernell, Lokusatu Heva Sumanadasa, Frederick James Alexander Thompson, David White, Leslie George Whitehead, Charles Harold Wigg.

Companion.—Charles G. K. Browne.

Associate Fellowship and Associate Membership Examinations

Examinations for Associate Fellowship and Associate Membership were held in the Offices of the Society on May 16th and 17th, 1935. The examinations of the Society are now held twice a year, in May and December.

The following satisfied the examiners in the subjects shown at the May, 1935, examination:—

ASSOCIATE FELLOWSHIP.

A. N. Bray	Pure Mathematics. Strength of Materials and Structures. Design (Aircraft).
D. R. H. Dickinson ...	Applied Mathematics. Strength of Materials and Structures. Theory of Internal Combustion Engines.
J. F. Foss	Strength of Materials and Structures. Aerodynamics.
D. S. Gunning	Pure Mathematics. Strength of Materials and Structures Aerodynamics.
J. C. Hardman	Pure Mathematics. Aerodynamics.
N. F. Newbery	Applied Mathematics. Strength of Materials and Structures. Theory of Internal Combustion Engines.
J. H. Stevens	Applied Mathematics.
C. O. Vernon	Pure Mathematics. Strength of Materials and Structures. Aerodynamics.
J. E. Walker	Applied Mathematics. Strength of Materials and Structures. Aerodynamics.
F. L. Weatherdon ...	Pure Mathematics. Strength of Materials and Structures. Design (Aircraft).
P. N. Willoughby ...	Aerodynamics.

ASSOCIATE MEMBERSHIP.

H. C. N. Barron ...	Applied Mathematics. Strength of Materials and Structures. Theory of Internal Combustion Engines.
C. R. P. Bizeray ...	Design (Aircraft).
A. St. H. Brock	Strength of Materials and Structures.
E. P. M. Keeling ...	Strength of Materials and Structures.
W. H. Newton	Applied Mathematics. Strength of Materials and Structures. Theory of Internal Combustion Engines.
A. M. Scott	Applied Mathematics. Strength of Materials and Structures. Theory of Internal Combustion Engines.
J. E. Shroff	Strength of Materials and Structures.
P. G. Wright	Applied Mathematics. Strength of Materials and Structures. Theory of Internal Combustion Engines.

Aircraft Conference

On July 10th, 11th and 12th, 1935, an Aircraft Conference was held by the Aeronautical Research Committee and the Royal Aeronautical Society. The object of the Conference was to discuss the present position of aeronautical

research in relation to the technical problems of the British aircraft industry. The Conference was held, by kind permission, at the City and Guilds Engineering College. There were Sessions as follows:—

Date.	Chairman.	Papers read by.
July 10th.	H. T. Tizard, Esq., C.B., F.R.Ae.S.	Major T. M. Barlow, M.Sc., M.Inst.C.E., F.R.Ae.S., on "Aeronautical Research and the Industry."
,, 11th.	Lieut.-Col. J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.P.	A. G. Elliott, Esq., on "Future Research for Water-Cooled Engines."
,, 11th.	Lieut.-Col. J. T. C. Moore-Brabazon.	A. H. R. Fedden, Esq., F.R.Ae.S., on "Future Research for Air-Cooled Engines."
,, 12th.	Sir Joseph Petavel, K.B.E., F.R.S., F.R.Ae.S.	A. Hessell Tiltman, Esq., F.R.Ae.S. on "Safety Problems of High Performance Aircraft."
,, 12th.	Sir Joseph Petavel.	F. Radcliffe, Esq., A.F.R.Ae.S., on "Safety Problems of High Performance Aircraft."
,, 12th.	Sir Joseph Petavel.	A. Gouge, Esq., B.Sc., F.R.Ae.S., on "Future Research on Flying Boats and Seaplanes."
,, 12th.	H. T. Tizard, Esq., C.B., F.R.Ae.S.	Summary of the Discussions.

Wilbur Wright Memorial Lecture and Conversazione, May 30th, 1935

A report of this is given in the November, 1935, Journal, page 1003.

Lectures

The following Lectures were read before the Society in 1935:—

January 7th.—"Imperial Air Routes," by Mr. C. F. Snowden Gamble.

February 8th.—"Ice Formation in Carburettors," by Mr. W. C. Clothier, M.Sc.

February 22nd.—"Research in the R.A.E. Tank," by Mr. L. P. Coombes, B.Sc., A.C.G.I.

March 1st.—"Fuels for Aircraft Engines," by Mr. E. L. Bass, A.F.R.Ae.S.

March 5th.—"Cold Pressing and Drawing," by Dr. A. Gough and Dr. Desch. (Joint Meeting with the Institution of Automobile Engineers and other bodies.)

March 12th.—"Recent Developments in the Lighting of Airways and Aerodromes," by Mr. H. N. Green. (Joint Meeting with the Illuminating Engineering Society.)

March 15th.—"New Developments in the Autogiro," by Senor Juan de la Cierva, F.R.Ae.S.

April 15th.—"Commercial Aircraft," by Captain G. de Havilland, C.B.E., F.R.Ae.S.

May 30th.—Twenty-third Wilbur Wright Memorial Lecture. "The Developments and Reliability of the Modern Multi-Engined Liner," by Mr. D. W. Douglas.

October 21st.—"Piloting Commercial Aircraft," by Major H. G. Brackley, D.S.O., D.S.C., F.R.G.S.

November 4th.—"The Prevention of Ice Accretion," by Mr. B. Lockspeiser, M.A.

November 18th.—" Cooling Problems with Particular Reference to the Work of the 24ft. R.A.E. Tunnel," by Dr. G. P. Douglas, M.C., A.F.R.Ae.S.

November 25th.—" Sound Proofing of Aircraft," by Dr. S. J. Zand.

December 2nd.—" Retractable Undercarriages," by Mr. G. H. Dowty, M.I.Ae.E., A.F.R.Ae.S.

December 16th.—" Wireless and its Application to Commercial Aviation," by Captain J. M. Furnival, M.B.E., A.F.R.Ae.S.

Branch Lectures

January 3rd.—Lecture before Gloucester and Cheltenham Branch on " High Duty Alloys," by Mr. W. C. Devereux, A.F.R.Ae.S.

January 3rd.—Lecture before the Yeovil Branch on " Compression Ignition Engines," by Mr. A. H. R. Fedden, M.B.E., M.I.A.E., M.S.A.E., F.R.Ae.S.

January 17th.—Lecture before the Coventry Branch on " The Autogiro," by Senor Juan de la Cierva, F.R.Ae.S.

January 17th.—Lecture before the Yeovil Branch on " Small Oil Engines for Road Transport," by Mr. H. O. Farmer, B.Sc., M.I.A.E.

January 24th.—Lecture before the Gloucester and Cheltenham Branch on " The Autogiro," by Senor Juan de la Cierva, F.R.Ae.S.

January 31st.—Lecture before the Yeovil Branch on " The Autogiro," by Senor Juan de la Cierva, F.R.Ae.S.

January 31st.—Lecture before the Gloucester and Cheltenham Branch on " Airport Development," by Squadron Leader Nigel Norman, A.F.R.Ae.S.

February 14th.—Lecture before the Gloucester and Cheltenham Branch, by Mr. H. J. Pollard, A.F.R.Ae.S., on " Metal Construction."

February 21st.—Lecture before the Coventry Branch, by Major H. N. Wylie, B.Sc., M.B.E., F.R.Ae.S.

February 21st.—Lecture before the Westland Aircraft Society (Yeovil Branch, R.Ae.S.), by Mr. E. F. Relf, A.R.C.Sc., F.R.Ae.S., on " Turbulence."

February 28th.—Lecture before the Gloucester and Cheltenham Branch, by Dr. L. Aitchison, on " Magnesium Alloys."

March 14th.—Lecture before the Yeovil Branch on " Test Flying," by Mr. H. J. Penrose, A.F.R.Ae.S.

March 14th.—Lecture before the Gloucester and Cheltenham Branch, by Mr. J. E. Hodgson, on " Some Pioneers of the Aeroplane."

March 17th.—Lecture before Woodford House School, Birchington, by Mr. E. W. Roberts.

March 21st.—Lecture before Coventry Branch on " Blind Flying and Navigation of Aircraft without External Visibility," by Flight Lieut. H. F. Jenkins.

September 26th.—Lecture before the Yeovil Branch (Westland Aircraft Society), by Captain J. Laurence Pritchard, on " The Stratosphere."

October 10th.—Lecture before the Yeovil Branch, by Mr. A. C. Hughes, on " Flying over the Empire."

October 24th.—Lecture before the Yeovil Branch, by Mr. H. Inman, on " Some Industrial Uses of the Oxy-Acetylene Blowpipe in Great Britain."

Nov. 5th.—Lecture before the Bristol Branch on " The Stratosphere," by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

Nov. 7th.—Lecture before the Yeovil Branch, by Mr. H. J. C. Harper and Flight Lieut. Kirk, on " Deck-Landing Aircraft."

Nov. 7th.—Lecture before the Portsmouth Branch, by Mr. R. H. Woodall, A.M.I.E.E., A.M.I.Ae.E., on " Electrical Equipment for Aircraft."

Nov. 21st.—Lecture before the Westland Branch, by Mr. H. A. Drane, on "Machine Tools for Small Batch Production."

Nov. 21st.—Lecture before the Portsmouth Branch, by Mr. W. Hackett, on "Tubes and Tube Manipulation."

Nov. 21st.—Lecture before the Coventry Branch, by Lieut. H. Cantrill, on "Carburation and Engine Controls."

Dec. 5th.—Lecture before the Westland Branch, by Mr. A. Davenport, F.R.Ae.S., on "Aircraft Design and its Practical Application."

Dec. 17th.—Lecture before the Bristol Branch, by Herr R. Kronfeld, on "Gliding."

Dec. 19th.—Lecture before the Coventry Branch, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "The Stratosphere."

Dec. 19th.—Lecture before the Portsmouth Branch, by Mr. H. J. Pollard, Wh. Ex., A.F.R.Ae.S., on "Metal Construction."

Dec. 19th.—Sound Pictures before the Westland Branch, by a Representative of the British Thomson Houston Company, Limited, Rugby.

Public Schools Lectures

The Council arranged for the fifth year in succession to give lectures before the Public Schools and other educational establishments. These lectures, all of which are illustrated by a large number of slides, usually between 40 and 50 for each lecture, are complete in themselves, so that lecturers have the minimum amount of trouble.

The Council particularly wish to thank all those members of the Society who have so willingly given up their leisure time to help by delivering one or more of these lectures. There is a greater demand for lectures than can be acceded to at present, and the Council urge any member who can help in this way, by giving a lecture before his old school or one in his neighbourhood, to volunteer their services. These lectures have now been given so regularly to many schools that they are eagerly looked forward to each year.

Lectures on any particular aspect of aviation, together with appropriate slides, can be prepared when necessary. The following is a list of the lectures at present available; each lecture is prepared so that it takes approximately one hour to deliver:—

No. 1.—The History of the Aeroplane.
No. 2.—The Aeroplane and its Uses.
No. 3.—Seaplanes and Flying Boats.
*No. 4.—How an Aeroplane is Made and Flies.
No. 5.—Training Pilots for the Royal Air Force.
No. 6.—The Imperial Air Routes.
No. 7.—A Trip into the Stratosphere.
No. 8.—How an Aeroplane Flies.
No. 9.—How an Aeroplane is Made.

* This lecture is a combination of lectures 8 and 9 for those who want both together. Certain matter and slides given in Nos. 8 and 9 have been omitted, so that the lecture takes no longer to deliver.

Lectures Before Public Schools, etc.

January 22nd.—Lecture to the Junior Imperial League, Welling, by Mr. E. W. Roberts, M.Sc.

January 26th.—Lecture to Herne Bay College, by Mr. E. W. Roberts, M.Sc.

January 28th.—Lecture to Nottingham High School, by Mr. G. R. Irvine, A.M.I.Ae.E.

January 28th.—Lecture to Itchen Secondary School, by Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S., M.I.Mech.E., M.I.N.A.

January 29th.—Lecture to Northampton Town and County School, by Mr. G. R. Irvine, A.M.I.Ae.E.

January 29th.—Lecture to Epsom College, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

January 29th.—Lecture to King Edward VI School, by Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S., M.I.Mech.E., M.I.N.A.

January 30th.—Lecture to Upton College, by Mr. E. W. Roberts.

January 31st.—Lecture to Peter Symond's School, Winchester, by Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S., M.I.Mech.E., M.I.N.A.

February 1st.—Lecture before the Scientific Society of Wakefield Grammar School, by Mr. G. C. F. Ely.

February 2nd.—Lecture before Eastbourne College, by Mr. G. R. Irvine, A.M.I.Ae.E.

February 6th.—Lecture to the Senior Scholars of Bilston Education Committee, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

February 8th.—Lecture before the City of Oxford High School for Boys, by Mr. A. F. Houlberg, A.M.I.Ae.E.

February 9th.—Lecture before Highgate School, by Mr. H. T. Winter, Founder Member.

February 20th.—Lecture before Wrekin College, by Major T. M. Barlow, F.R.Ae.S.

February 20th.—Lecture before Willaston School, Nantwich, by Mr. G. R. Irvine, A.M.I.Ae.E.

February 21st.—Lecture before the Woolwich Engineering Society, by Mr. R. A. Wilmshurst.

February 21st.—Lecture before King's School, Chester, by Mr. G. R. Irvine, A.M.I.Ae.E.

February 22nd.—Lecture before Durham School, by Dr. E. G. Richardson, Companion.

February 22nd.—Lecture before Mostyn House School, by Mr. G. R. Irvine, A.M.I.Ae.E.

March 1st.—Lecture before Cannock House School, Eltham, by Mr. R. A. Wilmshurst.

March 2nd.—Lecture before Herne Bay College, by Mr. E. W. Roberts.

March 5th.—Lecture before Birkenhead School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

March 5th.—Lecture before Hillingdon School, by Mr. J. T. Morton, A.M.I.Ae.E.

March 6th.—Lecture before Rossall School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

March 14th.—Lecture at Chiswick Public Library, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

April 5th.—Lecture before Gunnersbury Preparatory School by Mr. G. Waters.

April 16th.—Lecture before the Skybird League, at 3.30 p.m., by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

October 4th.—Lecture before University College School, by Mr. H. T. Winter, on "A Trip into the Stratosphere."

October 17th.—Lecture before the Kingswood Grammar School, Bristol, by Mr. W. Brierley, on "Training R.A.F. Pilots."

October 18th.—Lecture before Balshaw's Grammar School, by Captain J. Laurence Pritchard, on "A Trip into the Stratosphere."

October 18th.—Lecture before Durham School, by Mr. J. Bell, on "A Trip into the Stratosphere."

October 25th.—Lecture before Rutherford College, by Mr. J. Bell, on " A Trip into the Stratosphere."

October 25th.—Lecture before King's School, Rochester, by Mr. C. P. Lipscomb, on " The Imperial Air Routes."

October 26th.—Lecture before Caterham School, by Captain J. Laurence Pritchard, on " A Trip into the Stratosphere."

October 31st.—Lecture before Imperial Service College, by Lieut.-Commander the Hon. J. M. Southwell, on " The History of the Aeroplane."

Nov. 7th.—Lecture before Coatham School, by Mr. J. Bell, A.R.Ae.S.I., on " The Imperial Air Routes."

Nov. 15th.—Lecture before Gillingham School, by Mr. C. P. Lipscomb, A.F.R.Ae.S., on " A Trip into the Stratosphere."

Nov. 16th.—Lecture before Stamford School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on " How an Aeroplane is Made and Flies."

Nov. 16th.—Lecture before Berkhamstead School, by Mr. M. Langley, M.I.Ae.E., A.M.I.N.A., on " How an Aeroplane is Made and Flies."

Nov. 16th.—Lecture before Herne Bay College, by Mr. E. W. Roberts, on " Training R.A.F. Pilots."

Nov. 21st.—Lecture before City of London Freemen's School, by Mr. N. A. Champion, A.M.I.Ae.E., on " A Trip into the Stratosphere."

Nov. 21st.—Lecture before the Rotary Club of Leatherhead, by Mr. N. A. Champion, A.M.I.Ae.E., on " A Trip into the Stratosphere."

Nov. 22nd.—Lecture before St. Edmund's School, Canterbury, by Mr. E. W. Roberts, on " A Trip into the Stratosphere."

Nov. 26th.—Lecture at Kingston Public Library, by Mr. J. V. Connolly, B.E., A.F.R.Ae.S., on " The Uses of the Aeroplane."

Nov. 26th.—Lecture before the High School, Newcastle, Staffs., by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on " A Trip into the Stratosphere."

Nov. 27th.—Lecture before Upton College, by Mr. E. W. Roberts, on " A Trip into the Stratosphere."

Nov. 29th.—Lecture before King's School, Rochester, by Mr. C. P. T. Lipscomb, A.F.R.Ae.S., on " Imperial Air Routes."

Nov. 30th.—Lecture before Woodford House School, Birchington, by Mr. E. W. Roberts, on " A Trip into the Stratosphere."

Dec. 4th.—Lecture before St. Olave's School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on " Imperial Air Routes."

Dec. 4th.—Lecture before Annfield Plain Schools, by Dr. E. G. Richardson, on " How an Aeroplane is Made and Flies."

Dec. 4th.—Lecture before Germain's Senior Boys' School, by Captain A. B. Fanstone, A.F.C., M.A., A.F.R.Ae.S., on " How an Aeroplane is Made and Flies."

Dec. 6th.—Lecture before King's School, Ely, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on " How an Aeroplane is Made and Flies."

Dec. 9th.—Lecture before King Edward VI School, by Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S., on " The Imperial Air Routes."

Dec. 10th.—Lecture before Birkenhead School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on " A Trip into the Stratosphere."

Dec. 10th.—Lecture before Rossall School, Fleetwood, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on " How an Aeroplane is Made and Flies."

Students' Section

The following summarises the activities of the Students' Section for the Session 1934-35:—

The following officers and members of committee were elected at the Annual General Meeting on Thursday, October 4th, 1934:—Chairman—Mr. E. C. A. Backhaus; Vice-Chairman—Mr. R. L. Lickley; Hon. Secretary—Mr. R. W. Hase; Hon. Assistant Secretary—Mr. A. F. Walsh; Committee—R. K. Page, W. Tye, G. L. H. Bott, G. W. T. Champneys, C. H. Jackson.

The following meetings were held during the Session:—

Tuesday, Oct. 16th, 1934.—Inaugural Address, by Captain P. D. Acland, on "Some Aspects of Aviation." In the chair, Mr. H. E. Wimperis, C.B., C.B.E., F.R.Ae.S.

Tuesday, Oct. 30th, 1934.—"Aero Engines," by Mr. R. G. Jones. In the chair, Mr. E. Shaw, A.F.R.Ae.S.

Tuesday, Dec. 4th, 1934.—"Air Pilotage," by Mr. R. W. Hase. In the chair, Captain O. P. Jones.

Tuesday, Feb. 5th, 1935.—Informal Discussion on "The Training of the Aeronautical Engineer from the Students' Point of View." In the chair, Mr. E. C. A. Backhaus.

Tuesday, Feb. 19th, 1935.—"Some Notes on Spinning of Aeroplanes," by Mr. R. K. Page. In the chair, Mr. R. P. Alston.

Tuesday, March 19th, 1935.—"Steels Used in Aircraft Construction," by Mr. R. L. Lickley. In the chair, Professor F. T. Hill, F.R.Ae.S., M.I.Ae.E.

Tuesday, April 16th, 1935.—"The International Challenge de Tourisme, 1934," by Mr. W. D. McPherson. In the chair, Mr. R. L. Lickley.

Tuesday, April 30th, 1935.—"Variable Pitch Airscrews (with Special Reference to the Ratier as Used on the D.H. 'Comet')," by Mr. R. A. P. Misra. In the chair, Dr. H. C. Watts, M.B.E., F.R.Ae.S.

The average attendance at these meetings was 22.

Visits were made to the following works and aerodromes:—

Hawker Aircraft, Ltd.
Sperry Gyroscope Co., Ltd.
Short Brothers, Ltd.
D. Napier and Sons, Ltd.
Heston Airport.

Mr. R. W. Hase unfortunately had to retire from the position of Secretary at the beginning of February, and his place was taken by Mr. A. F. Walsh, the Assistant Secretary.

The attendances at the meetings throughout the Session have been very poor in proportion to the membership of the Students' Section, and the Committee have considered means of increasing these attendances during the next Session. It is to be hoped that students will take a keener interest in the forthcoming Session's activities.

Awards

The following awards were made during the year:—

Society's Silver Medal.—C. C. Walker, F.R.Ae.S., A.M.Inst.C.E.
Major F. B. Halford, F.R.Ae.S.

Simms Gold Medal.—Dr. L. Aitchison, B.Sc., F.I.C.

Taylor Gold Medal.—F. Rodwell Banks, O.B.E., F.R.Ae.S., A.M.I.Aut.E.

Busk Memorial Prize.—H. Roxbee Cox, Ph.D., D.I.C., B.Sc., A.F.R.Ae.S.

Akroyd Stuart Memorial Prize.—A special award of 25 guineas to Mr. E. E. Chatterton, B.Sc., A.F.R.Ae.S.

Elliott Memorial Prize.—Sergeant-Apprentice P. Wykeham-Barnes and Sergeant-Apprentice J. A. Pitcairn-Hill, of Halton (half share each), and Sergeant-Apprentice D. C. Maybury, of Halton.

Acknowledgments

The Council gratefully acknowledge the following:—

Back numbers of the Journal from Miss A. D. Betts (Companion), Miss G. Cottrell (Companion), Mr. G. W. Hart (Founder Member), Mr. W. G. Kentfield (Associate Member), Mr. H. J. Mackintosh, Dr. G. Merton, Mr. T. B. Ringwood (Associate Member), Mr. F. P. Walsh (Associate Fellow), Sir E. Owen Williams (Associate Fellow), Mr. J. Zeidenfeld, the Aircraft Operating Company and the Association of Special Libraries and Information Bureaux.

Lantern slides from Mr. E. L. Bass (Associate Fellow), Major J. S. Buchanan (Fellow), Air Commodore J. A. Chamier (Associate Fellow), Captain J. Durward (Associate Fellow), Dr. W. H. Hatfield (Associate Fellow), Mr. W. O. Manning (Fellow), the Air League of the British Empire, the Blackburn Aeroplane and Motor Company, Limited, Imperial Airways, Limited, the National Geographical Society of America and the Society of British Aircraft Constructors.

Library books, publications and periodicals from Captain S. L. Collins, Captain J. Durward (Associate Fellow), Mr. J. V. Holman (Associate), Professor M. Kondo, Mr. W. O. Manning (Fellow), Major R. H. Mayo (Fellow), Sqdn. Ldr. E. J. D. Townesend (Associate Fellow), Mr. M. H. Voik (Associate Fellow), the "Aeroplane" and the Society of British Aircraft Constructors.

Endowment Fund

The Council gratefully acknowledge one guinea each from Mr. A. J. Henington (Associate Member) and Mr. J. W. C. Logan (Associate Member) to the Endowment Fund.

Assistant to the Secretary

Mr. William Rea McWilliam was appointed Assistant to the Secretary in January, 1935.

Corrections

In the paper on "High Speed Aircraft Design," by R. M. Clarkson, published in the March Journal, it was stated that all the photographs were due to the courtesy of *Flight*. Three photographs on pages 225-6 were by courtesy of the *Aeroplane*, one on page 222 by courtesy of Fox Photos, and others on pages 218, 220 and 221 by courtesy of the de Havilland Aircraft Co.

Garden Party

The Society held a Garden Party on Sunday, May 5th, 1935, at the Great West Aerodrome, near Hayes, by kind permission of Mr. C. R. Fairey, Past-President of the Society. The Garden Party proved to be one of the most successful events of the year and was attended by over 1,500 members and their guests. Much of the success was due to the very great help of Mr. Fairey and his staff, who organised the greater part of the arrangements at the aerodrome. The flying arrangements were in the hands of Flt.-Lieut. C. S. Staniland, and particular thanks are due to him for the highly efficient and excellent organisation which he arranged.

The Council wish to put on particular record the very great debt which the Society owes to its Past-President, Mr. Fairey, who not only gave the Society free use of his magnificent aerodrome for the day, but freed the Society of all other costs in connection with the Garden Party.

The Council also wish to thank all those who so willingly contributed towards making the Garden Party the great success it was. The following is the programme which was arranged:—

2.30—3.10 p.m.—Reception by the President, Lieut.-Colonel J. T. C. Moore-Brabazon and Council.

FLYING PROGRAMME.

3.15 p.m.—Flt.-Lieut. Clarkson. Comper Swift (Pobjoy).
3.25 p.m.—Flt.-Lieut. Turner-Hughes. Armstrong Whitworth Scimitar (Panther VI).
3.35 p.m.—Mr. Collins (London Gliding Club) will arrive from Reading on his glider, the "Rhonadler."
3.50 p.m.—Flt.-Lieut. P. G. Lucas. Hawker Hart (Rolls-Royce Kestrel VI).
4 p.m.—Parachute jumping arranged by Irving Air Chute Company of Great Britain, Ltd. Parachutist, Mr. F. C. Coveney.
4.10 p.m.—Tea interval.
4.40 p.m.—Flt.-Lieut. T. Rose. Miles Hawk (Gipsy) (Phillips and Powis Aircraft Limited).
4.50 p.m.—Flt.-Lieut. J. B. Wilson. Klemm Swallow (Pobjoy Cataract).
5 p.m.—Tea interval.
5.30 p.m.—Mr. H. A. Marsh. Cierva Autogiro (Genet).
5.40 p.m.—Flt.-Lieut. C. S. Staniland. Fairey Firefly II (R.R. Kestrel II S).
5.50 p.m.—Mr. C. A. Washer. Bristol Bulldog Mk. II A (Jupiter VI).
6 p.m.—Flt.-Lieut. H. M. Schofield (General Aircraft). Monospar S.T.12 (Gipsy Major).
6.10 p.m.—Fire display demonstration by the Bells Asbestos Company Limited.

During the afternoon there were exhibitions by Mr. Thorn, of A. V. Roe and Company Limited, of crazy flying.

The following machines, in addition to those of private owners arriving by air, were on the aerodrome:—

Airspeed Courier (Lord Ronaldshay).
Airspeed Envoy.
Armstrong Scimitar.
Avro Commodore (Henleys Limited).
B.A.C. Drone (Mr. Kronfeld).
Bristol Bulldog.
Carden Aeroplane-glider (retractable engine and propeller).
De Havilland Gipsy Moth I (Miss Jean Batten).
De Havilland Leopard Moth.
De Havilland Puss Moth (Lord Sempill).
De Havilland Puss Moth (Mr. W. D. MacPherson).
De Havilland Dragon.
De Havilland Rapide.
De Havilland 86.
Douglas Air Liner (K.L.M.).
Fairey Aviation Company's Hendon Bomber.
Fairey Seal Seaplane.
Hawker Hart.
Klemm Eagle.
Miles Falcon.

Monospar S.10 (General Aircraft Limited).
Northrop Air Liner (by permission of the Air Ministry).
Percival Gull.
Saunders Roe Saro Cloud Amphibian.
Short Bros. Scion (Henleys Limited).
Spartan Cruiser.

In the hangar of the Fairey Aviation Company, the Royal Aeronautical Society showed a selection of photographs of aircraft of the past twenty-five years, and a series of historical prints from the collection of Mr. J. E. Hodgson, Honorary Librarian of the Society.

The following firms very kindly helped in the display in the hangar:—

Aircraft Components Limited (Working Units of Retracting Undercarriage and Tail Wheels, etc.).
Bristol Aeroplane Company (Engines).
Dunlop Rubber Company Limited (Accessories).
Henry Hughes and Son Limited (Instruments).
Model Transport Company Limited (Aircraft and Aero Engine Models).
D. Napier and Son Limited (Dagger Engine).
Plessey Company Limited (Wireless Apparatus).
Reid and Sigrist Limited (Reid Reaction Apparatus and Instruments).
Rolls Royce Limited (Engine).
Simmonds Aerocessories Limited (Aerocessories).
Fairey Aviation Company Limited (Airscrews, Floats, High-speed Gun Mounting, Accessories).
Tecalemit Limited (Accessories).
Air Survey Company and Williamson Manufacturing Company (Photographs and Cameras).
Marconi Wireless Telegraph Company Limited (Wireless Equipment).
Irving Air Chute Company of Great Britain Limited (Parachutes).
Smiths Aircraft Instruments (Instruments).
Short and Mason Limited (Instruments).
Mr. J. Allen (Model Aircraft, 1909-1934).

The loud speaker equipment was provided by the Standard Telephones and Cables Company Limited, and Flt.-Lieut. R. L. Ragg broadcast the programme of events and necessary announcements throughout the afternoon.

During the afternoon, the Central Band of H.M. Royal Air Force (by permission of the Air Council), under the direction of Flt.-Lieut. R. P. O'Donnell, M.V.O., Director of Music, R.A.F., played a series of selections.

The following is a list of members and guests who attended the Royal Aeronautical Society's Garden Party on Sunday, May 5th, 1935, at the Great West Aerodrome:—

R. C. Abel, Esq.; Miss F. M. B. Abel; C. F. Abell, Esq., O.B.E., A.F.R.Ae.S. (and three guests); Major G. H. Abell, O.B.E., A.F.R.Ae.S.; Mrs. G. H. Abell; Miss Abell; Miss Pam Abell; Captain P. D. Acland; Miss Anne Acland; S. J. D. Acland, Esq.; Flight Commander Acland; David R. Adams, Esq., A.F.R.Ae.S.; Mrs. David R. Adams; H. F. Adams, Esq.; Mrs. H. F. Adams; N. K. Adams, Esq.; E. N. Adlington, Esq. (and three guests); E. Ainsworth, Esq.; Aircraft Distributors, Limited (four guests); Capitaine de Corvette V. A. M. Albertas (French Air Attaché); Madame Albertas; R. M. Alcock, Esq., A.F.R.Ae.S.; G. W. Aldridge, Esq.; Captain W. Algie, D.S.O.; Mrs. Algie; Dr. F. M. Allchin; W. Allchin, Esq.; Wing Commander D. L. Allen, A.F.C., A.R.Ae.S.I.; Mrs. D. L. Allen; B. S. Allen, Esq.; Mrs. Allen; Miss A. D. Allmand; Major J. W. Kidston Allsopp, M.Inst.C.E., A.F.R.Ae.S.

(and two guests); Miss Alston; the Rt. Hon. Lord Amulree, P.C., G.B.E., K.C.; Herman Andreae, Esq.; Mrs. Herman Andreae; S. V. Appleby, Esq.; Colonel Argal; Mrs. Argal; Captain Natal Arnaud (Brazilian Assistant Naval Attaché); Madame Natal Arnaud; M. B. Arpin, Esq.; R. Ashton, Esq., A.R.Ae.S.I.; Mrs. R. Ashton; J. R. Ashwell-Cooke, Esq. (and three guests).

Major B. F. S. Baden-Powell, F.R.A.S., F.R.Met.Soc., Hon. F.R.Ae.S.; H. Bailey, Esq., A.F.R.Ae.S.; Captain V. H. Baker; Air Commodore J. E. A. Baldwin, D.S.O., O.B.E., A.F.R.Ae.S. (and four guests); Major C. J. P. Ball, D.S.O., M.C., A.F.R.Ae.S. (and seven guests); F. J. Ballard, Esq., A.R.Ae.S.I.; F. Rodwell Banks, Esq., O.B.E., F.R.Ae.S.; Mrs. Rodwell Banks; Miss J. Barber; F. Barber, Esq.; Mrs. Barber; Major T. M. Barlow, M.Sc., M.Inst.C.E., F.R.Ae.S.; Mrs. Barlow; Master T. Vincent Barlow; Captain F. S. Barnwell, O.B.E., A.F.C., F.R.Ae.S.; R. A. Barnwell, Esq.; E. A. S. Barnard, Esq.; Wallace Barr, Esq. (and one guest); A. Golding Barrett, Esq.; Miss Peggy Barrett; R. Barratt, Esq.; T. B. Barrington, Esq.; F. S. Barton, Esq. (and one guest); Miss M. Barton; Miss F. Barwood; E. L. Bass, Esq., A.F.R.Ae.S.; Mrs. Bass; H. Beamish, Esq. (and three guests); J. H. E. Beard, Esq.; Fred Beard, Esq.; Lieut.-Commander T. R. Beatty, R.N.; Mrs. Beatty; Lord Beaverbrook; Her Grace the Duchess of Bedford, D.B.E.; Major F. C. Bedwell; Mrs. F. C. Bedwell; H. Belart, Esq., A.F.R.Ae.S.; His Excellency the Belgian Ambassador (Baron de Carter de Marchienne); Sir Arthur Shirley Benn, K.B.E., M.P.; E. N. B. Bentley, Esq., A.F.R.Ae.S.; G. N. B. Bentley, Esq.; — Bentley, Esq.; H. C. Bergel, Esq.; Mrs. Bergel; J. Bharuipa, Esq.; J. Myles Bickerton, Esq.; Mrs. Myles Bickerton; E. H. Biggs, Esq.; Major Basil Binyon, O.B.E., A.F.R.Ae.S.; Mrs. G. E. Binyon; H. D. Binyon, Esq.; Miss M. H. Binyon; Terence Bird, Esq.; Flt. Lieut. G. Birkett; Robert Blackburn, Esq., O.B.E., F.R.Ae.S., M.I.M.E.; A. Blyth, Esq.; Mrs. Blyth; — Bond, Esq.; Mrs. Bond; D. Bonney, Esq.; Mrs. Bonney; F. G. Boreham, Esq., A.R.Ae.S.I.; Mrs. A. M. Boreham; Air Vice-Marshal A. E. Borton, C.B., D.S.O., A.F.C. (and two guests); Flt. Lieut. K. L. Boswell, A.F.R.Ae.S.; Mrs. Boswell; K. Boswell, Esq.; W. H. Botssord, Esq.; W. H. Boultwood, Esq.; I. Bowen, Esq., M.Sc., A.F.R.Ae.S. (and one guest); Air Vice-Marshal F. W. Bowhill, C.M.G., D.S.O., R.A.F. (Air Member for Personnel); Mrs. Bowhill; E. C. Bowyer, Esq.; Mrs. E. C. Bowyer (and two guests); L. Boyce, Esq., M.P.; Mrs. Boyce; G. Boyd, Esq.; F. D. Bradbrooke, Esq. (and one guest); W. P. Bradbury, Esq.; Mrs. Bradbury; Miss F. B. Bradfield, M.A., A.F.R.Ae.S.; Mrs. Bradfield (and three guests); Miss M. Bradley; M. L. Bramson, Esq., A.C.G.I., F.R.Ae.S., A.M.I.M.E. (and guest); Griffith Brewer, Esq. (and three guests); Squadron Leader Briddon; R. A. C. Brie, Esq.; Captain Briggs (and two guests); Group Captain E. F. Briggs, D.S.O., O.B.E., F.R.Ae.S. (and one guest); Mrs. E. F. Briggs; Master M. F. Briggs; Steven J. Bristow, Esq.; W. A. Bristow, Esq., M.I.E.E., M.I.A.E., F.R.Ae.S. (and three guests); Air Commodore H. Le M. Brock, C.B., D.S.O.; Mrs. H. Le M. Brock; Miss Anne Brock; Master J. Brock; Master W. Brock; Air Chief Marshal Sir Robert Brooke-Popham, K.C.B., C.M.G., D.S.O., A.F.C., F.R.Ae.S.; Lady Brooke-Popham; C. H. Brooks, Esq., A.F.R.Ae.S. (and three guests); — Brown, Esq.; Mrs. Brown; D. L. Brown, Esq., Assoc.M.Inst.C.E., A.F.R.Ae.S.; E. C. Brown, Esq., A.R.Ae.S.I.; Mrs. E. C. Brown; Eric Gore-Browne, Esq.; Mrs. Gore-Browne; Thomas Gore-Browne, Esq.; R. M. Brutnall, Esq.; Squadron Leader G. M. Bryer, O.B.E., A.F.C.; Mrs. Bryer; R. G. Buck, Esq. (and one guest); Major G. P. Bulman, O.B.E., B.Sc., F.R.Ae.S.; Mrs. Bulman; Lieut.-Colonel H. Burchall, D.S.O.; Mrs. Burchall; Squadron Leader C. G. Burge, O.B.E., A.R.Ae.S.I. (and two guests); A. F. Burke, Esq.; D. W. Burland, Esq.; Mrs. D. W. Burland; Victor Burnett, Esq. ("Sunday Express"); A. S. Butler, Esq. (and two guests); Mrs. Butler; Captain L. C. Bygrave.

Colonel W. Caldwell; Mrs. Caldwell; S. Camm, Esq., F.R.Ae.S.; Mrs. H. R. Camm; Miss Phyllis Camm; J. D. Campbell, Esq., B.Sc., A.F.R.Ae.S. (and two guests); Campbell-Orde, Esq.; P. D. Canning, Esq.; Master Canning; R. S. Capon, Esq., O.B.E., B.A., F.R.Ae.S.; Mrs. R. S. Capon, Sir John V. Carden (and four guests); Lady Carden; B. C. Carter, Esq., F.R.Ae.S.; Mrs. B. C. Carter; Dr. D. S. Cassidy; Mrs. D. S. Cassidy; Air Commodore H. M. Cave-Browne-Cave, D.S.O., D.F.C., F.R.Ae.S. (and one guest); Mrs. Chalmers; Dr. T. W. Chalmers (and one guest); Air Commodore J. A. Chamier, C.B., C.M.G., D.S.O., O.B.E., R.A.F. (ret.), (Secretary, Air League of the British Empire); Mrs. J. A. Chamier (and two guests); Master J. E. Chamier; Master P. A. Chamier; — Chapleo, Esq.; Mrs. Chapleo; K. W. Chapman, Esq.; P. Chapman, Esq.; P./O. H. F. Chester; J. E. Chorlton, Esq.; Flt. Lieut. C. Clarkson; F. J. Cleveland, Esq., A.M.I.Ae.E. (and two guests); Miss Cleveland; Master Cleveland; Lord Clifton; A. C. Clinton, Esq., A.F.R.Ae.S.; Mrs. A. C. Clinton; R. Cluer, Esq.; E. H. Cochrane, Esq. (and two guests); Squadron Leader S. N. Cole, A.F.R.Ae.S. (and one guest); W. S. Coleman, Esq.; C. M. Collard, Esq.; H. W. Collard, Esq.; Mrs. H. W. Collard; College of Aeronautical Engineering, Chelsea (27 guests); Miss Collins; Mr. Collins; Flt. Lieut. C. H. A. Colman; Miss Cooper; Miss Cooper; Major J. P. C. Cooper, O.B.E., M.C.; Mrs. Cooper (and three guests); Captain J. H. Cordes, R.A.F.O. (and two guests); A. Cornthwaite, Esq.; B. Cornthwaite, Esq.; Miss G. Cottrel; William Courtney, Esq. (and three guests) ("Evening Standard"); W. B. Cowan, Esq.; Mrs. W. B. Cowan; Miss Beatrice Cowley; H. Roxbee Cox, Esq., Ph.D., D.I.C., B.Sc., A.F.R.Ae.S.; Mrs. Roxbee Cox; A. Knight Croad, Esq., A.F.R.Ae.S.; Mrs. A. Knight Croad; Miss Irene Croad; G. T. Croad, Esq.; A. T. Cross, Esq., A.F.R.Ae.S.; Mrs. A. T. Cross; P. G. Cunningham, Esq.; J. F. Cuss, Esq.; Miss I. M. Cuss.

"Daily Express"; Miss Gabriel Dakeyne; Miss Helen Dakeyne; Hon. A. Dalrymple; Lieut.-Colonel M. O. Darby, O.B.E. (and seven guests); J. F. Davey, Esq.; Dr. Neilson Davie; Mrs. Neilson Davie; Henry Davies, Esq., B.A., A.F.R.Ae.S. (and one guest); W. E. Davis, Esq.; Mrs. W. E. Davis; M. J. B. Davy, Esq., A.F.R.Ae.S.; Graham R. Dawbarn, Esq., M.A., F.R.I.B.A., M.I.Struct.E., A.F.R.Ae.S.; Mrs. Graham Dawbarn; Mr. Dawes; P. Dawson, Esq.; R. B. Dealey, Esq.; R. P. G. Denman, Esq., A.F.R.Ae.S. (and eight guests); Gerald d'Erlanger, Esq.; Mrs. d'Erlanger; W. C. Devereux, Esq., A.F.R.Ae.S.; Mrs. Devereux; J. P. Dewsberry, Esq.; Lieut.-Commander A. E. M. Dodington; G. P. Douglas, Esq., D.Sc., M.C., A.F.R.Ae.S. (and three guests); Air Marshal Sir Hugh C. T. Dowding, K.C.B., C.M.G., p.s.c. (Air Member for Research and Development); Master Dowding; T. Downing, Esq.; Mrs. Downing; G. H. Dowty, Esq., A.F.R.Ae.S., M.I.Ae.E.; M. A. Doyle, Esq., B.Sc., A.F.R.Ae.S. (and two guests); Mrs. Dreschfield (and one guest); Kathleen Countess of Drogheda (and one guest); P. Dubash, Esq.; Jack E. Duckham, Esq.; Mrs. J. E. Duckham; T. Dunans, Esq., D.Sc.; Mrs. Dunans; Miss M. Durrant; C. Dutton, Esq.

— Elliot, Esq.; J. B. Elliot, Esq.; Mrs. Elliot; — Ellis, Esq.; Mrs. Ellis (and two guests); — Ellison, Esq.; Mrs. Ellison; Miss Betty Engall; E. C. Gordon England, Esq., F.R.Ae.S.; Mrs. Gordon England; G. Gordon England, Esq.; Miss D. Gordon England; S. H. Evans, Esq., M.I.Ae.E., A.F.R.Ae.S. (and three guests); W. M. Evans, Esq.

C. R. Fairey, Esq., M.B.E., F.R.Ae.S.; R. Fairey, Esq., Jnr. (and nine guests); R. Falk, Esq.; V. M. Falkner, Esq., A.F.R.Ae.S.; Mrs. V. M. Falkner; Miss A. Farrington; Miss F. Farrington; A. H. R. Fedden, Esq., F.R.Ae.S.; Lieut.-Col. L. F. R. Fell, D.S.O., O.B.E., M.I.Mech.E., F.R.Ae.S.; Miss Fernie; W. Fernie, Esq.; C. R. Field, Esq.; J. Field, Esq.; Mrs. Figgures; E. G. Fischeles, Esq.; W. L. Fisher, Esq.; Commander Fleiuss; Representative of "Flight"; Captain Carl Florman and lady; H. P. Folland, Esq., M.B.E.,

F.R.Ae.S. (and one guest); H. R. Foottit, Esq.; Captain A. G. Forsyth; Mrs. A. G. Forsyth; Master R. Forsyth; John Fox, Esq.; H. E. Fozard, Esq., M.B.E., A.M.I.Mech.E., A.F.R.Ae.S.; J. F. Fowkes, Esq.; H. W. Franklin, Esq., B.A., A.F.R.Ae.S.; Mrs. H. W. Franklin; R. H. Franklin, Esq.; Mrs. R. H. Franklin; Eric Frost, Esq.; Roger Fuller, Esq. ("Daily Mail"); Mrs. Fuller; Captain J. M. Furnival, M.B.E., A.F.R.Ae.S. (and one guest).

Lieut.-Commander B. W. Galpin, R.N. (and two guests); C. F. Snowden Gamble, Esq.; Flt. Lieut. G. L. Gandy, A.R.Ae.S.I.; Mrs. G. L. Gandy; S. E. Garcke, Esq. (President, Institute of Transport); Mrs. S. E. Garcke; Miss A. Gardner; Group Captain A. G. R. Garrod, M.C., D.F.C., A.R.Ae.S.I.; Master Peter Garrod; W. C. Gaskin, Esq.; Mrs. Gaskin; V. S. Gaunt, Esq. (and two guests); General Aircraft (four guests); M. Gervassy; Colonel Geyr; Lieut.-Col. E. Gheorghiu (Roumanian Air Attaché); John Grierson, Esq. (and one guest); F. Gillett, Esq.; Mrs. F. Gillett; Captain H. R. Gillman, A.F.R.Ae.S. (Secretary, Society of British Aircraft Constructors); Mrs. Gillman; K. B. Gillmore, Esq.; Lieut.-Col. E. Gold, D.S.O., F.R.S. (President, Royal Meteorological Society); Mrs. Gold; E. Godivala, Esq.; A. G. Gooch, Esq.; Sir Ralph Gore; Lady Gore; Lord Gorell, C.B.E., M.C. (Chairman, Royal Aero Club); Lady Gorell; W. G. Gould, Esq., A.M.Inst.N.A., A.F.R.Ae.S.; R. Graham, Esq.; Mrs. R. Graham; Miss Graham; K. W. C. Grand, Esq.; Mrs. Grand; W. E. Gray, Esq. (and one guest); C. G. Grey, Esq. (Editor, "The Aeroplane," and two guests); Mrs. C. G. Grey; C. W. T. Grey, Esq.; Captain L. Grey-Sykes; Mrs. L. Grey-Sykes; W. H. Grieve, Esq.; C. H. Griffiths, Esq.; Mrs. C. H. Griffiths; P. T. Griffith, Esq., A.F.R.Ae.S.; Mrs. Griffith; H. Grinsted, Esq., O.B.E., B.Sc., F.R.Ae.S.; Brig.-Gen. P. R. C. Groves, C.B., C.M.G., D.S.O., A.F.R.Ae.S. (and seven guests); Captain the Rt. Hon. F. E. Guest, C.B.E., D.S.O., M.P. (and guest); Miss Gullick; Lady Gunter; D. Guyler, Esq.; Miss Guyler.

Geoffrey Hall, Esq. (and one guest); Francis Hancock, Esq.; Mrs. Hancock; P. J. Hannon, Esq., M.P.; Mrs. Hannon; M. Harvey, Esq.; D. H. Handover, Esq.; Mrs. Handover; J. C. Hardman, Esq.; J. L. Harrington, Esq.; Mrs. Harrington; Sir Harold Hartley (Vice-President, L.M. & S. Rly.); Lady Hartley; R. K. Hase, Esq. (and four guests); Captain G. de Havilland, O.B.E., A.F.C., F.R.Ae.S.; Mrs. G. de Havilland; C. Haydon, Esq.; Mrs. Haydon; R. M. Hayes, Esq. (and one guest); Miss P. Hellyer; Squadron Leader W. Helmore, M.Sc., A.F.R.Ae.S.; H. Hemming, Esq., A.F.C., F.R.Ae.S. (and four guests); A. J. Henington, Esq. (and seven guests); M. Herrod-Hempsall, Esq.; Baron von Herwarth, Esq.; Dr. A. C. Hewer; Mrs. Hewer; Professor G. T. R. Hill, M.C., M.Sc., F.R.Ae.S.; Professor F. T. Hill, F.R.Ae.S., M.I.Ae.E.; Mrs. Hill; Miss A. M. I. Hill; R. F. Hill, Esq.; Lady Hill; Flt. Lieut. L. Massey Hilton, D.F.C., A.F.C., A.R.Ae.S.I. (and three guests); L. P. Hirsch; R. Hoar, Esq.; Mrs. R. Hoar; L. E. Hoddle, Esq.; Frank Hodges, Esq.; Mrs Frank Hodges; A. D. Hodgson, Esq., A.M.I.E.E., A.F.R.Ae.S.; Mrs. Hodgson; J. E. Hodgson, Esq., Hon. F.R.Ae.S.; Mrs. Hodgson; John L. Hodgson, Esq., B.Sc., A.F.R.Ae.S.; Master Gordon H. Hodgson; E. Hogg, Esq.; Mrs. E. Hogg; Commander N. Holbrook, V.C. (and three guests); E. Holroyd, Esq., A.F.R.Ae.S.; Miss Homan; M. S. Hooper, Esq., A.F.R.Ae.S.; Mrs. M. S. Hooper; Miss Maureen Hooper; F. Campbell Hopcraft, Esq.; F. W. Hopcraft, Esq. (four tickets); Edward Hopkins, Esq., A.R.Ae.S.I.; Mrs. E. Hopkins; Miss M. M. Hopkins; Sir Frederick Gowland Hopkins, M.A., D.Sc. (President, Royal Society); Lady Gowland Hopkins; I. G. Hopkinson, Esq. (and one guest); G. E. Horne, Esq. (and one guest); F. J. Horn, Esq.; H. B. Howard, Esq., B.A., B.Sc., F.R.Ae.S.; Mrs. Howard; L. A. Howard, Esq.; Miss M. Howard; Miss Howe; Hans Hoygaard, Esq.; Arthur J. Hughes, Esq., O.B.E., A.F.R.Ae.S. (and three guests); Mr. Hughes; Turner Hughes, Esq.; Mrs. Turner Hughes; R. A. Humble, Esq., A.R.Ae.S.I.; Mrs. Humble; Miss Elizabeth

Humble; Miss E. Humphreys; Miss Humphries; S. Humphries, Esq.; Mrs. Humphries (and two guests); Mr. Hunter; C. P. Hunter, Esq.; Wing Commander B. L. Huskisson, R.N.; Group Captain G. B. Hynes, D.S.O., R.A.F. (and one guest).

A. Ignatieff, Esq.; Air Commodore A. W. Iredell, M.R.C.S., L.R.C.P., K.H.P. (Director of R.A.F. Medical Services); Mrs. Iredell; Leslie L. Irvin, Esq.; G. R. Irvine, Esq., A.M.I.Ae.E. (and one guest); Miss Irvine; H. B. Irving, Esq., B.Sc., F.R.Ae.S.; Mrs. Irving (and two guests); A. C. T. Isaac, Esq., A.M.I.Mech.E., A.R.Ae.S.I.; Mrs. A. Isaac; I. Israel, Esq.

A. C. M. Jackaman, Esq., A.M.I.Ae.E.; Miss Jackaman; A. C. Jackson, Esq., B.Sc., A.F.R.Ae.S.; C. H. Jackson, Esq. (and one guest); Mrs. E. E. James; Thurstan James, Esq.; Mrs. Thurstan James; D. M. Jameson, Esq., Miss F. Jarvis (and one guest); W. E. P. Johnson, Esq., A.F.C., F.C.I.P.A., A.F.R.Ae.S., R.A.F.O.; J. L. B. Jones, Esq., B.Sc. (and one guest); Lingham Jones, Esq. (and one guest); A. S. Jupitus, Esq.

W. Kaeppeli, Esq.; Engineer Commander Y. Kano; Captain Karklin; C. Kauffman, Esq.; Mrs. Kauffman; A. J. Keating, Esq.; R. C. Kemp, Esq.; Mrs. R. C. Kemp; Miss S. T. Kemp; Master R. I. C. Kemp; Master D. C. Kemp; Major D. H. Kennedy, O.B.E., F.R.Ae.S. (and twelve guests); Mrs. Kennedy; Miss Kennedy; J. Kenworthy, Esq., B.Sc., A.F.R.Ae.S.; Mrs. Kenworthy; E. P. King, Esq., B.Sc., A.F.R.Ae.S. (and two guests); F. R. B. King, Esq.; Miss King; R. D. King, Esq.; Mrs. R. D. King; E. Kleynot, Esq.; E. Gibson Knight, Esq., A.F.R.Ae.S.; Mrs. G. M. Knight; J. K. Knight, Esq.; Commander V. L. Kopio (Roumanian Air Attaché); Madame Kopio; Iver Krabbe, Esq.; Mrs. Iver Krabbe; — Krayenhoff, Esq.; Herr Kronfeld; Mrs. Kronfeld.

Dr. G. V. Lachmann, A.F.R.Ae.S.; Mrs. Lachmann; J. E. Lamb, Esq., A.M.I.Ae.E.; Mrs. Lamb; Captain A. G. Lamplugh, F.R.Ae.S., M.I.Ae.E.; Mrs. Lamplugh; — Lane, Esq.; Mrs. Lane; M. Langley, Esq., M.I.Ae.E.; Mrs. Langley; W. Lappin, Esq. (and seven guests); — Lappin, Esq.; Mrs. Lappin; J. H. B. Larrad, Esq., A.F.R.Ae.S. (and three guests); L. Larsen, Esq.; J. A. Latty, Esq.; H. Lavender, Esq.; Mrs. H. Lavender; C. W. Lawson, Esq.; J. W. Leach, Esq.; E. J. H. Lemon, Esq.; Miss Joan Lemon; Squadron Leader Leslie, D.S.C.; Mrs. Leslie; D. A. Letts, Esq.; Captain H. S. Leverton; Miss Adeline Levinson; R. L. Lickley, Esq.; Kenneth Lindsay, Esq., M.P.; R. N. Liptrot, Esq., B.A.; D. D. Little, Esq.; Mrs. Little; Major Alan Lloyd (and three guests); Lloyds List Representative; R. Loader, Esq. (and one guest); C. N. H. Lock, Esq., M.A., F.R.Ae.S.; Walter F. Lock, Esq. (and one guest); Miss Lomer; the Most Hon. the Marquess of Londonderry, K.G., M.V.O. (Secretary of State for Air); Miss Ruth Long; David Longden, Esq., M.I.Ae.E. (and three guests); John Lord, Esq., F.R.Ae.S.; Mrs. Lord; Frank Lord, Esq.; Eric Lord, Esq.; John Lord, Esq., Jnr.; M. Loveday, Esq.; H. C. Luttman, Esq., B.A., A.R.Ae.S.I.; Mrs. Luttman; A. H. Lynch, Esq. (and one guest); Gerald Lyon, Esq., M.Sc., A.F.R.Ae.S.; A. M. Lyons, Esq., M.P. (and one guest);

W. Mabane, Esq., M.P. (and one guest); Sir Francis McClean, A.F.C., A.F.R.Ae.S.; Lady McClean; Miss Iona McClean; Ivor McClure, Esq. (and one guest); Wing Commander B. McEntegart (and two guests); W. A. McKenzie, Esq. (and one guest), Allied Newspapers; Sir Robert McLean; J. W. Maccoll, Esq., B.Sc., Ph.D., A.F.R.Ae.S.; Miss Maccoll; Miss J. Macdonald; R. Macdonald, Esq., M.A.; Dr. E. B. MacGinty; Colonel E. E. B. Mackintosh, D.S.O. (Director, Science Museum); Mrs. Mackintosh; J. Mackintosh, Esq.; Commander L. D. Mackintosh, D.S.C., A.F.R.Ae.S. (and three guests); Captain N. Macmillan, A.F.C., A.F.R.Ae.S. (and two guests); W. D. Macpherson, Esq.; W. R. McWilliam, Esq.; Mrs. McWilliam; W. Rea McWilliam, Esq.; J. A. McWilliam, Esq.; His Excellency the Soviet Ambassador

(Monsieur Maisky); Madame Maisky; W. L'Estrange Malone, Esq.; Brig.-Gen. H. O. Mance, K.B.E., C.B., C.M.G., D.S.O.; Lady Mance; H. Mance, Esq.; G. H. Mansell, Esq. (and six guests); J. A. C. Manson, Esq., B.Sc., A.F.R.Ae.S.; Mrs. J. A. C. Manson; His Excellency the Belgian Ambassador (Baron de Cartier de Marchienne); Baroness de Cartier de Marchienne; A. E. Marsden, Esq., A.F.R.Ae.S.; Mrs. Marsden; Miss L. Marsh (and two guests); R. Holland-Martin, Esq.; Mrs. Holland-Martin; Lieut.-Col. M. Maruyama (Japanese Military Attaché); Miss M. Mason; E. Matthews, Esq.; Mrs. Matthews; Captain Matthew; Mrs. Matthew; Master Matthew; R. Borlase Matthews, Esq., Wh.Ex., M.I.E.E., Assoc.M.Inst.C.E., F.R.Ae.S.; Miss Matthews; Mr. Matthews, Jnr.; Algernon Maudslay, Esq. (with two guests); I. C. Maxwell, Esq.; Miss Ursula Ross May; Major R. H. Mayo, O.B.E., M.A., F.R.Ae.S.; Mrs. Mayo; Wing Commander A. H. Measures, O.B.E.; Mrs. Measures; Miss Measures; Captain Manuel Medina (Spanish Naval Attaché); Mdlle. Medina; Mrs. Mellor; John Millar, Esq.; D. P. Milne, Esq.; R. A. P. Misra, Esq.; Miss T. Mitchell; J. A. Mollison, Esq.; Mrs. J. A. Mollison; Captain J. W. Monahan (Air Attaché, U.S. Embassy) (and one guest); C. Montgomery, Esq.; Lieut.-Col. J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.I.Ae.E., M.P. (President of the Royal Aeronautical Society); Mrs. Moore-Brabazon; Miss Moore-Brabazon; M. J. Moore-Brabazon, Esq.; D. C. Moore-Brabazon, Esq.; H. G. Morcom, Esq., A.F.R.Ae.S.; Master R. H. Morcom; L. R. Morphew, Esq.; Miss M. E. Morphew; Miss C. E. Morris; H. H. Morris, Esq.; Mrs. Morris; R. Morris, Esq.; C. F. Morrison, Esq.; Mrs. C. F. Morrison; Miss Pamela Morse; S. R. Mullard, Esq., M.B.E., M.I.E.E.; Mrs. Mullard; Senorita Constancia Muller; F. A. I. Muntz, Esq., B.A., A.M.I.A.E., A.F.R.Ae.S.; Lady Margaret Muntz; W. D. Murray, Esq., A.F.R.Ae.S.; Mrs. L. E. Murray.

P. P. Nazir, Esq., A.F.R.Ae.S.; C. H. Latimer-Needham, Esq., M.Sc., F.R.Ae.S. (and three guests); N. D. New, Esq.; Air Vice-Marshal C. L. N. Newall, C.B., C.M.G., C.B.E. (Air Member for Supply and Organisation); Mrs. Newall; H. C. Newton, Esq., A.M.I.Ae.E.; Mrs. Newton; Miss M. Newton; J. Newton, Esq.; Charles E. Nicholson, Esq.; C. Nicholson, Esq.; Mrs. Nicholson; Y. Nitta, Esq.; Kenneth Noel, Esq. (and one guest); Miss Rosalind Norman; H. N. St. V. Norman, Esq., B.A., F.R.Ae.S.; Mrs. Norman (and four guests); Charles North, Esq. (and one guest); N. S. Norway, Esq., B.A., A.F.R.Ae.S.; Mrs. Norway; C. R. Curtiss Nuthall, Esq.; Major General A. Nyssens (Belgian Military Attaché); Madame A. Nyssens.

R. O'Donnell, Esq.; B. O'Donnell, Esq.; Mrs. O'Donnell; Commander D. W. Ogg; Mrs. D. W. Ogg; Flt. Lieut. Ogilvie-Forbes, B.A., A.F.R.Ae.S (and one guest); Mr. Ortelius; Mrs. Ortelius; G. E. Orton, Esq.; Mrs. Orton; Engineer-Commander S. Otiai (Japanese Naval Attaché); Lieut.-Col. H. W. S. Outram, C.B.E., A.F.R.Ae.S. (and four guests); Mrs. Outram; E. Ower, Esq., B.Sc., A.F.R.Ae.S. (and three guests); A. Ozersky, Esq.; Madame A. Ozersky.

Dudley Page, Esq. (and one guest); F. Handley Page, Esq., C.B.E., F.R.Ae.S.; Mrs. F. Handley Page; Miss Page; W. M. Page, Esq. (Educational Adviser to the Air Ministry); Mrs. Page; R. K. Page, Esq.; Messrs. Pakenham; Miss Parker; Miss Sylvia Parkes; Miss J. Rosalind Parkes; — Parkes, Esq.; Miss Y. Parlett; M. Parmentier; R. J. Parrott, Esq.; Mrs. R. J. Parrott; A. T. Penman, Esq. (and one other, Reuters); E. W. Percival, Esq., M.I.Ae.E. (and one guest); H. E. Perrin, Esq. (Secretary, Royal Aero Club); Mrs. Perrin; — Perry, Esq.; S. C. Perry, Esq.; Dr. G. Petit; G. E. Petty, Esq., A.F.R.Ae.S.; E. L. Pickles, Esq., O.B.E., A.F.R.Ae.S. (and one guest); Dr. N. A. V. Piercy, A.M.Inst.C.E., F.R.Ae.S., M.I.Mech.E.; Mrs. Piercy; C. A. Pike, Esq., A.F.R.Ae.S.; Mrs. Pike; F. Pilling, Esq., A.M.I.N.A., A.F.R.Ae.S.; Mrs. Pilling; F. Ping, Esq.; E. Pitman, Esq. (and ten guests); A. Plesman, Esq.; Mrs. Plesman; D. R. Pobjoy, Esq.;

Bill Porter, Esq. (and one other); A. Postnikow, Esq.; F. R. Potter, Esq.; Miss Potter; Squadron Leader C. H. Potts, A.F.R.Ae.S.; C. M. Poulsen, Esq. (Technical Editor, " Flight "); R. A. Powell, Esq., A.F.R.Ae.S.; Mrs. R. A. Powell; C. O. Powis, Esq.; Press Association; Flt. Lieut. R. C. Preston, A.F.C., A.M.I.Ae.E.; Mrs. Preston; R. L. Preston, Esq., A.F.R.Ae.S.; Mrs. Preston; Captain J. Laurence Pritchard, Hon. F.R.Ae.S. (Secretary, Royal Aeronautical Society); Mrs. J. Laurence Pritchard; Master J. D. Pritchard; Group Captain Primrose; Mrs. Primrose; C. Protheroe, Esq., A.R.Ae.S.I.; Mrs. Protheroe; E. E. Pugh, Esq.; Mrs. E. E. Pugh; Miss L. M. Pulleine; General V. K. Putna; Madame Putna; H. J. Pye, Esq.; Mrs. H. J. Pye.

Miss Dorothy Quartley; A. J. Quin-Harkin, Esq.; Mrs. Quin-Harkin.

R. Rainey, Esq.; P. H. Rayner, Esq. (and one guest); G. H. N. Read, Esq.; O. Reder, Esq.; Sir Richard Redmayne, K.C.B., M.Sc. (President of the Institution of Civil Engineers); Lady Redmayne; C. W. Reeve, Esq.; Mrs. C. W. Reeve; Colonel J. D. K. Restler, F.R.Ae.S.; Mrs. Restler (with the three Misses Restler); Miss D. Rhodes; Mrs. I. L. Rhodes; D. Rhodes, Esq.; R. G. Rhodes, Esq.; Miss Eileen Rice; L. J. H. Richards, Esq., A.F.R.Ae.S.; H. N. B. Richards, Esq., A.M.I.Ae.E.; Victor A. Ricketts (" Daily Express "); T. W. Rippingale, Esq.; Miss Roberts; F. Roberts, Esq.; J. V. Roberts, Esq., A.R.Ae.S.I. (and four guests); Major F. A. de V. Robertson, M.A.; Air Commodore E. D. M. Robertson, D.F.C.; Mrs. Robertson; C. P. Robertson, Esq., M.B.E.; Mrs. Robertson; Captain H. S. Robertson; Sir Macpherson Robertson; Lady Robertson; C. S. Robinson, Esq.; Dr. Robinson; H. Rogers, Esq.; Lord Ronaldshay; L. A. Rumbold, Esq.; Mrs. Rumbold; Leslie Russell, Esq.

John Saffery, Esq.; S. Sanders, Esq.; the Rt. Hon. Sir Philip Sassoon, Bart., G.B.E., C.M.G., M.P. (Under-Secretary of State for Air); Squadron Leader Sanceau; Mrs. Sanceau; R. J. W. Sands, Esq.; W. P. Savage, Esq., A.F.R.Ae.S.; Mrs. Savage; Eric Shaw, Esq., A.F.R.Ae.S.; Dr. A. H. van Scherpenberg (Secretary, German Embassy); Frau van Scherpenberg; R. J. Schmidt, Esq.; Flt. Lieut. H. N. Schofield (and four guests); R. Scott, Esq.; Miss W. Scott; S. Scott-Hall, Esq., A.C.G.I., M.Sc., D.I.C., A.F.R.Ae.S., W. A. Seabrook, Esq., B.Sc., A.F.R.Ae.S.; Major T. P. Searight, A.F.R.Ae.S.; Lord Sempill, A.F.C., F.R.Ae.S. (and two guests); Captain Senkowski; Lieut.-Col. F. C. Shelmerdine, C.I.E., O.B.E., A.F.R.Ae.S. (Director-General of Civil Aviation); Mrs. Shelmerdine; N. Shelmerdine, Esq.; Mrs. N. Shelmerdine; B. S. Shenstone, Esq., A.F.R.Ae.S. (and one guest); E. Colston Shepherd, Esq. (" The Times "); Mrs. Colston Shepherd; Major B. W. Shilson, O.B.E., M.I.Mech.E., A.F.R.Ae.S. (and fifteen guests); Lieut.-Commander J. H. W. Shirley, R.N.; Mrs. Shirley; J. Shroff, Esq.; Sir John D. Siddeley, C.B.E., J.P., F.R.Ae.S.; Lady Siddeley; A. E. Simmonds, Esq., F.R.Ae.S., M.I.Ae.E., M.P.; Mrs. Simmonds; Frederick R. Simms, Esq., M.I.M.E., M.I.A.E., M.I.E.E., M.I.Ae.E.; Mrs. Simms; Mr. Simms; Mr. Sinclair; Miss Susan Slade; S. W. Slaughter, Esq., A.R.Ae.S.I.; Mrs. Slaughter; E. Sloternaker, Esq.; Crawfurth Smith, Esq. (Reuters); G. Geoffrey Smith, Esq.; Mrs. Geoffrey Smith; Sir Harold Smith; Lady Gengoult Smith; Miss R. E. Smith; S. O. Smith, Esq., A.F.R.Ae.S.; Mrs. Smith; Miss Smith; G. J. Smith-Pert, Esq.; M. L. Sodhi, Esq. (and one guest); M. Sokoloff, Esq.; R. J. W. Sounds, Esq.; — Speed, Esq.; Mrs. Speed; T. Stanhope Sprigg, Esq. (and two guests); — Stace, Esq.; Mrs. Stace; R. S. Stafford, Esq., A.F.R.Ae.S. (and one guest); H. Staines, Esq.; R. Stanley, Esq.; — Stead, Esq.; Mrs. Stead; A. Stenning, Esq.; A. B. Stenning, Esq.; Lieut.-Commander L. C. Stevens (Naval Attaché, American Embassy); Mrs. L. C. Stevens; Major Stewart; Mrs. Stewart; Major Oliver Stewart, M.C., A.F.C. (" Morning Post "); H. J. Stieger, Esq., D.I.C., A.F.R.Ae.S.; Mrs. Stieger; Captain R. H. Stocken, M.I.Ae.E.; Mrs. R. H. Stocken; Lord Stonehaven, P.C., G.C.M.G., C.M.G., D.S.O., J.P., D.L., LL.D.

(President, Institution of Naval Architects); Whitney Straight, Esq.; A. H. Stratford, Esq.; Commander U. Sugimoto, I.J.N.; Hubert Sutton, Esq., M.Sc., F.R.Ae.S.; Mrs. Sutton; Master Alan Sutton; — Symons, Esq.; Mrs. Symons; Lieut.-Col. Gilbert S. Szlumper, C.B.E.; Mrs. G. S. Szlumper.

W. F. Tamblin, Esq., A.M.I.N.A., A.F.R.Ae.S. (and one guest); Nigel Tangye, Esq.; O. J. Tapper, Esq. (and one guest); A. G. Taylor, Esq.; M. F. Taylor, Esq., A.R.C.M.; Air Commodore A. W. Tedder, p.s.c. (Director of Training, R.A.F.); Mrs. A. W. Tedder; F. M. Thomas, Esq., A.F.R.Ae.S. (and one guest); H. J. Thomas, Esq. (Chairman, Society of British Aircraft Constructors); Mrs. H. J. Thomas; J. P. Thompson, Esq.; Oliver Thornycroft, Esq., O.B.E., A.F.R.Ae.S.; Mrs. Oliver Thornycroft; Miss Olivia Thornycroft; Miss Priscilla Thornycroft; S. H. Tiltman, Esq.; — Titler, Esq.; Mrs. Titler; Miss Titler; F. W. Tonkin, Esq. (Australian Newspapers Cable Service); G. W. Topping, Esq.; Commander E. D. Toren (Swedish Air Attaché); Madame E. D. Toren; Dr. H. C. H. Townend, F.R.Ae.S.; M. H. Townley, Esq.; Lieut. Tracey; Mrs. Tracey; Major C. C. Turner, A.F.R.Ae.S.; Colonel Turner, D.S.O. (Director of Works and Buildings, Air Ministry); T. H. Turner, Esq., M.Sc., A.R.Ae.S.I.; W. Tye, Esq.; P. Tyson-Woodcock, Esq.

Captain C. F. Uwins, A.F.R.Ae.S.; Mrs. Uwins.

E. G. Vardy, Esq., B.Sc.; W. G. Venner, Esq.; Sir Alliott Verdon-Roe, Kt., O.B.E., F.R.Ae.S., M.I.Ae.E. (and three guests); G. N. Verver, Esq.; Air Commodore R. H. Verney, O.B.E. (Director of Technical Development, Air Ministry) (and nine guests); C. Amherst Villiers, Esq.; Major O. G. C. Villiers, D.S.O. (and one guest); Patrick N. Vincent, Esq.; Mrs. Vincent; Miss Vincent; W. Voice, Esq.; A. Volin, Esq.; M. H. Volk, Esq., A.F.R.Ae.S.; Miss B. Voyce; C. Cowles Voysey, Esq.; Mrs. C. Cowles Voysey.

Mr. Waddington; J. Waddington, Esq. (and one guest); C. C. Walker, Esq., A.M.Inst.C.E., F.R.Ae.S.; Mrs. C. C. Walker; David Walker, Esq.; P. Walker, Esq.; P. B. Walker, Esq.; M.A., Ph.D., A.F.R.Ae.S.; Miss Sybil Walker; R. W. Walker, Esq., A.F.R.Ae.S. (and four guests); Miss D. Wall; J. D. Walsh, Esq.; Lieut. E. H. Walter; Mrs. Walter; R. W. Walker, Esq. (and four guests); A. F. Walsh, Esq.; Captain Charles E. Ward; R. H. Warde, Esq.; Captain Michael Wardell; Captain Wassner; Mdme. Wassner; G. O. Waters, Esq.; Mrs. Waters; A. E. Watson, Esq., M.I.Struct.E.; Mrs. Watson; A. G. Watson, Esq.; J. A. V. Watson (and one guest); H. C. Watts, Esq., M.B.E., D.Sc., Assoc.M.Inst.C.E., F.R.Ae.S.; Mrs. Watts; Miss E. Weinstein; Air Commodore J. G. Weir, C.M.G., C.B.E., F.R.Ae.S. (and three guests); E. Weiser, Esq., B.Sc., D.I.C., A.F.R.Ae.S.; P. J. J. Weiss, Esq.; E. J. Weiss, Esq.; — Westbrook, Esq.; F. W. Westley, Esq., A.F.R.Ae.S. (and one guest); T. P. Wheeler, Esq.; Master B. N. White; Mrs. J. White; Flying Officer J. B. T. White, A.R.Ae.S.I.; David Whitelaw, Esq.; R. Wild, Esq.; Flying Officer R. L. Wilkinson; O. H. Williams, Esq.; Colin M. Williamson, Esq., O.B.E. (and one guest); Miss J. Williamson; Miss N. Williamson; D. L. Hollis Williams, Esq., B.Sc., A.F.R.Ae.S. (and three guests); P. N. Willoughby, Esq. (and seven guests); Mrs. Wills; Howard A. Wills, Esq.; Colonel L. M. Wilson, C.M.G., D.S.O., A.R.Ae.S.I.; Mrs. L. M. Wilson; P. J. Wilson, Esq.; R. E. Wilson, Esq.; H. E. Wimperis, Esq., C.B.E., M.A., M.I.E.E., F.R.Ae.S. (Director of Scientific Research, Air Ministry); Mrs. Wimperis (and niece); Miss Wimperis; L. A. Wingfield, Esq., M.C., D.F.C., A.R.Ae.S.I.; Mrs. L. A. Wingfield; C. G. H. Winter, Esq. (and one guest); H. T. Winter, Esq.; Mrs. D. M. Winter; Master John Winter; Miss M. Withy; C. J. Wood, Esq.; J. D. Wood, Esq.; L. J. Cardew Wood, Esq., A.C.G.I., B.Sc., A.F.R.Ae.S.; Mrs. L. J. C. Wood; Commander E. W. Woodruff, R.N. (ret.); Laurie Woods, Esq.; E. A. Wright, Esq.; Squadron Leader M. E. A. Wright, A.F.C., A.F.R.Ae.S.; Philip Wright, Esq.; Major H. N. Wylie, B.Sc., F.R.Ae.S.

D. D. Youngs, Esq.; Captain Young; Mrs. Young; Captain F. T. Young.

Obituaries

The Council greatly regret to record the deaths of the following members of the Society:—

MAJOR-GENERAL SIR RICHARD M. RUCK, K.B.E., C.B., C.M.G., *Fellow*, 1851-1935.

Richard Matthews Ruck was born on May 27th, 1851, and joined the R.E. in 1871. In 1881 he became Assistant Instructor at the School of Military Engineering in charge of the Submarine Mining School at Gillingham, and was promoted to Captain in 1883. In 1891 he was appointed Inspector of Submarine Defences. In 1896 Ruck was promoted to Lieutenant-Colonel and in 1902 recalled to the War Office to take up the appointment of Deputy Inspector-General of Fortifications. In 1908 Ruck became Major-General and retired at his own request in 1912.

On the outbreak of the Great War his extremely valuable experience was at once made use of. He was appointed Chief Engineer of the Central Force, an organisation of Territorial units for the defence of London and the coast from the Wash to Portsmouth, and in 1916 G.O.C. London defences.

Major-General Ruck was keenly interested in aviation and as early as 1905, when asked his opinion, made the remarkable forecast "that he was confident that in the early future the question of military supremacy would be decided by fighting in the air." He joined the Society in 1911 and became Chairman of Council in 1912, a post he held until 1919. In 1920 he became a Vice-President.

General Ruck served on the Council during some of the most difficult years of the Society and was one of the most hard working members. He rarely failed to attend either the meetings of Council or the lectures, busy though he was in many other directions, and by his advice and initiative he did much to raise the prestige of the Society. It was during his term of office as Chairman that the Society was granted the prefix of Royal. He was Vice-President of the Air Inventions Committee under the Air Ministry and a member of the first Civil Aerial Transport Committee. In 1920 he received the well-deserved rank of K.B.E. for his work on aeronautics.

His death on March 18th, 1935, was felt keenly by a very wide circle of friends. Quietly efficient it can be well said of him that he made no enemies.

ERIC STUART BRUCE, M.A. (Oxon)., F.R.Met.Soc.

Eric Stuart Bruce was the Honorary Secretary of the Society from January 1900 to January 1908, taking over the duties of Honorary Secretary from Major Baden-Powell. He was elected a member of the Society in 1886, and from the beginning took an active and practical interest in aviation. He wrote and read a number of papers before the Society, including "Portable Electric Balloon Signalling in War" (on which he also lectured before La Société Francaise de Aerienne in 1900); "The Meteo-Parachute," a self-acting parachute for returning to earth recording instruments carried by pilot balloons; "The Shape of Navigable Balloons"; "Registration (Pilot) Balloons in America"; "The Aeroplane Experiments of M. Santos Dumont," and many others. It was during his term of office that the first heavier-than-air flight was made, and Bruce saw the fulfilment of much of what had been speculation in the early years of his membership of the Society.

Owing to the increasing calls of business, he resigned the Honorary Secretaryship in 1908 and the following letter was written to him:—

> "My dear Bruce,—I am desired by the Council of the Aeronautical Society of Great Britain to express their most sincere and deep regret that you have decided, in view of your increasing private affairs, to resign the office of Hon. Secretary to the Society, for you have during your term of office

(which practically covers seven years) brought the Society from a comparative state of penury to that of comparative affluence. On behalf of this Society, allow me to express our most grateful thanks for your great past services, and to express a hope that you will still continue to aid our work by continuing on the Committee of the Society.

Believe me,

Yours very truly,

(Signed) FRANCIS TROLLOPE, Lt.-Col., *Vice-President.*"

For some years afterwards Stuart Bruce continued to take an active interest in the Society and its work, and for all his life in aviation—in which he had seen such remarkable progress. He died on February 28th, 1935.

AIR VICE-MARSHAL SIR VYELL VYVYAN, K.C.B., *Fellow.*

Arthur Vyell Vyvyan was born on March 12th, 1875, and first went to sea as a midshipman in the Camperdown in 1891. The following year he joined the ill-fated Victoria which was sunk by his former ship. He took firsts in seamanship, pilotage and torpedo work, and was promoted lieutenant in 1896 and took part in the Benin Expedition of 1897. In 1906 he was promoted commander, and in December, 1908, he became the first commander of the new battle-cruiser Invincible. In January, 1913, he was appointed assistant to the Chief of the War Staff, Admiralty, and in the following June promoted Captain and given command of one of the new light cruisers allocated to the First Light Cruiser Squadron, Grand Fleet. In March, 1915, he went out to Gallipoli as Beach Master at Anzac during the landing on April 25th, 1915, for which services he was awarded the D.S.O.

On January 16th, 1916, he was appointed to the Air Department at the Admiralty, as Assistant to the Superintendent of Aircraft construction. Following the establishment of the R.A.F. in 1918, he became senior R.A.F. Officer in the Mediterranean. In 1919 he became the first Air Officer Commanding the Coastal Area, a command he held for five years. He retired the year following his relinquishing this post, on September 1st, 1925, and was appointed one of the Government Directors of Imperial Airways. In April, 1929, he flew with the first regular air mail service to India and back in 15 days, and in January, 1932, he opened the regular weekly service between Croydon and Cape Town. He was created K.C.B. in 1923 and received many foreign decorations.

For many years Sir Vyell Vyvyan was a Member of Council of the Society, in whose work he took the keenest possible interest. He was a great enthusiast for civil aviation and did a great deal by his practical example to promote its welfare. He died on September 30th, 1935, after only a few weeks' illness.

E. J. H. LYNAM, A.R.C.Sc., D.I.C., *Fellow.*

E. J. H. Lynam became a trade lad by competitive examination at Woolwich Arsenal in September, 1908. After completing his training he attended a course at the Royal College of Science, of which he became an Associate. In 1915 Lynam entered the R.A.E. as a draughtsman, and his outstanding abilities rapidly gained him promotion. In 1918 he became head of the Airscrew Design Section, a position he held until September, 1926. In the reorganisation of the Airworthiness Department he was promoted to Principal Technical Officer in Charge. In 1932 he became Chief Technical Officer of the Aeroplane and Armament Experimental Establishment, a position he held until the time of his death on June 4th, 1935, at the early age of 42.

By his death aviation lost one of its most brilliant technical men whose opinions, though often opposed, were respected by all with whom he came in contact. He became an Associate Fellow in 1918 and a full Fellow in 1932.

CAPTAIN LEONARD CHARLES BYGRAVE, M.B.E., A.M.I.E.E., *Fellow*, 1892-1935.

Leonard Charles Bygrave, who died as the result of a riding accident on September 6th, 1935, was head of the Instrument and Physics Department, at the Royal Aircraft Establishment, Farnborough. He had been employed in the Directorate of Scientific Research at the Air Ministry since its formation, after serving in the Royal Air Force and in the Department of the Director-General of Supply and Research. He joined the Society in 1921 as an Associate Fellow and became a full Fellow in 1932. Bygrave's name is associated with a number of instruments and his early death was a severe loss.

JOHN KITCHING, F.R.G.S., F.L.S., *Founder Member*.

John Kitching, who died on March 28th, 1935, was a Founder Member of the Society, joining in 1908, when the Wright Brothers were astonishing the world by their flying exploits in France. He had a very wide variety of interests and was a member of many learned societies, but his early interest in aviation never wavered, and at one time he was a constant attender at the Society's lectures.

LAWRENCE PILKINGTON HIRSH, R.A.F.O., *Associate*, 1903-1935.

L. P. Hirsh died on September 5th, 1935, following a motor accident. Educated at Birkenhead School, he served in the R.A.F. from 1922-29 and then joined the Imperial Airways (Administrative Board) Europe and Africa, 1930-1932. In the later year he joined Airports, Ltd. He became an Associate of the Society in 1935.

FRANK G. DUNCANSON, B.Sc., Wh. Ex., *Associate Fellow*, 1889-1935.

F. Duncanson, who became an Associate Fellow in 1930 and died in November of 1935, took his engineering degree at London University and after some years' apprenticeship in marine engineering turned to aeronautical engineering. He became assistant designer at the Gloster Aircraft Company, Ltd.

N. HOGMAN.

N. Hogman was elected a student of the Society in 1931 and died on June 3rd, 1935.

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No. 492, Tests of Sixteen Related Airfoils at High Speeds, John Stack and Albert E. von Doenhoff.

No. 493, The Physical Effects of Detonation in a Closed Cylindrical Chamber, C. S. Draper.

No. 494, A Flight Investigation of the Lateral Control Characteristics of Short Wide Ailerons and Various Spoilers with Different Amounts of Wing Dihedral, Fred. E. Weick, H. A. Soule and Melvin N. Gough.

No. 495, A Description and Test Results of a Spark-Ignition and a Compression-Ignition Two-Stroke-Cycle Engine, J. A. Spanogle and E. G. Whitney.

No. **496**, General Theory of Aerodynamic Instability and the Mechanism of Flutter, Theodore Theodorsen.

No. **497**, Computation of the Two-Dimensional Flow in a Laminar Boundary Layer, Hugh L. Dryden.

No. **498**, Improved Airplane Windshields to Provide Vision in Stormy Weather, William C. Clay.

No. **499**, Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. XII.—Upper-Surface Ailerons on Wings with Split Flaps, Fred. E. Weick and Carl J. Wenzinger.

No. **500**, The Influence of Tip Shape on the Wing Load Distribution as Determined by Flight Tests, Richard V. Rhode.

No. **501**, Relative Loading on Biplane Wings of Unequal Chords, Walter S. Diehl.

No. **502**, Scale Effect on Clark Y Airfoil Characteristics from N.A.C.A. Full-Scale Wind-Tunnel Tests, Abe Silverstein.

No. **503**, The Effect of Spray Strips on the Take-off Performance of a Model of a Flying-Boat Hull, Starr Truscott.

No. **504**, On the Theory of Laminar Boundary Layers Involving Separation, Th. von Kármán and C. B. Millikan.

No. **505**, Tests of Nacelle-Propeller Combinations in Various Positions with Reference to Wings. IV.—Thick Wing—Various Radial-Engine Cowlings—Tandem Propellers, James G. McHugh.

No. **506**, Tests of Nacelle-Propeller Combinations in Various Positions with Reference to Wings. V.—Clark Y Biplane Cellule—N.A.C.A. Cowled Nacelle—Tractor Propeller, E. F. Valentine.

No. **508**, Analysis of Two-Spar Cantilever Wings with Special Reference to Torsion and Load Transference, Paul Kuhn.

No. **509**, General Equations for the Stress Analysis of Rings, Eugene E. Lundquist and Walter F. Burke.

No. **510**, Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. XIII.—Auxiliary Airfoils Used as External Ailerons, Fred. E. Weick and Richard W. Noyes.

No. **511**, The Effect of Baffles on the Temperature Distribution and Heat-Transfer Coefficients of Finned Cylinders, Oscar W. Schey and Vern. G. Rollin.

No. **512**, Some Factors Affecting Combustion in an Internal-Combustion Engine, A. M. Rothrock and Mildred Cohn.

No. **513**, Experimental Investigation of the Robinson-Type Cup Anemometer, M. J. Brevoort and U. T. Joyner.

No. **514**, The Measurement of the Field of View from Airplane Cockpits, Melvin N. Gough.

No. **515**, Full-Scale Wind-Tunnel Tests of a PCA-2 Autogiro Rotor, John B. Wheatley and Manley J. Hood.

No. **516**, Potential Flow About Elongated Bodies of Revolution, Carl Kaplan.

No. **517**, Flight Investigation of Lateral Control Devices for Use with Full-Span Flaps, H. A. Soule and W. H. McAvoy.

No. **519**, Spinning Characteristics of Wings. I.—Rectangular Clark Y Monoplane Wing, M. J. Bamber and C. H. Zimmerman.

No. **521**, An Analysis of Longitudinal Stability in Power-Off Flight with Charts for Use in Design, Charles H. Zimmerman.

No. **523**, The Influence of Wing Setting on the Wing Load and Rotor Speed of a PCA-2 Autogiro as Determined in Flight, John B. Wheatley.

No. **524**, A Turbulence Indicator Utilising the Diffusion of Heat, G. B. Schubauer.

No. **525**, Some Effects of Injection Advance Angle, Engine-Jacket Temperature, and Speed on Combustion in a Compression-Ignition Engine, A. M. Rothrock and C. D. Waldron.

No. **526**, Noise from Two-Blade Propellers, E. Z. Stowell and A. F. Deming.

No. **527**, Air Flow in a Separate Laminar Boundary Layer, G. B. Schubauer.

No. **531**, The Effect of Water Vapour on Flame Velocity in Equivalent CO–O_2 Mixtures, Ernest F. Fiock and H. Kendall King.

No. **532**, The Soap-Bubble Method of Studying the Combustion of Mixtures of CO and O_2, Ernest F. Fiock and Carl H. Roeder.

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No. **504**, Complete Tank Tests of Two Flying-Boat Hulls with Pointed Steps—N.A.C.A. Models 22-A and 35, James M. Shoemaker and Joe W. Bell.

No. **505**, The Effects of Full-Span and Partial-Span Split Flaps on the Aerodynamic Characteristics of a Tapered Wing, Carl J. Wenzinger.

No. **506**, Experimental Verification of Theodorsen's Theoretical Jet-Boundary Correction Factors, George van Schliestett.

No. **507**, The Effects of Equal-Pressure Fixed Slots on the Characteristics of a Clark Y Airfoil, Albert Sherman and Thomas A. Harris.

No. **508**, Landing Characteristics of an Autogiro, William C. Peck.

No. 509, Tank Tests of Flat and V-Bottom Planing Surfaces, James M. Shoemaker.

No. 510, The Calculated Effect of Trailing-Edge Flaps on the Take-off of Flying Boats, J. B. Parkinson and J. W. Bell.

No. 511, A Study of the Pitching Moments and the Stability Characteristics of Monoplanes, George J. Higgins.

No. 512, A Complete Tank Test of the Hull of the Sikorsky S-40 Flying-Boat—American Clipper Class, John R. Dawson.

No. 513, The Wave Suppressors Used in the N.A.C.A. Tank, Starr Truscott.

No. 514, Effect of Combustion-Chamber Shape of the Performance of a Pre-Chamber Compression-Ignition Engine, C. S. Moore and J. H. Collins.

No. 515, Aerodynamic Effects of a Split Flap on the Spinning Characteristics of a Monoplane Model, M. J. Bamber.

No. 516, Propeller Vibrations and the Effect of the Centrifugal Force, T. Theodorsen.

No. 517, The Aerodynamic Forces and Moments on a Spinning Model of the F4B-2 Airplane as Measured by the Spinning Balance, M. J. Bamber and C. H. Zimmerman.

No. 518, Performance Tests of a Single-Cylinder Compression-Ignition Engine with a Displacer Piston, C. S. Moore and H. H. Foster.

No. 519, Vortex Noise from Rotating Cylindrical Rods, E. Z. Stowell and A. F. Deming.

No. 520, Calculations of the Effect of Wing Twist on the Air Forces Acting on a Monoplane Wing, G. Datwyler.

No. 521, Full-Scale Force and Pressure-Distribution Tests on a Tapered U.S.A. 45 Airfoil, John F. Parsons.

No. 522, Tank Tests of a Model of a Flying-Boat Hull with a Fluted Bottom, John R. Dawson.

No. 523, Strength Tests of Thin-Walled Duralumin Cylinders in Combined Transverse Shear and Bending, Eugene E. Lundquist.

No. 524, Wind-Tunnel Tests of a Wing with a Trailing-Edge Auxiliary Airfoil Used as a Flap, Richard W. Noyes.

No. 525, The Aerodynamic Drag of Flying-Boat Hull Models as Measured in the N.A.C.A. 20ft. Wind Tunnel, E. P. Hartman.

No. 526, Spinning Characteristics of Wings. II.—Rectangular Clark Y Biplane Cellule, M. J. Bamber

No. 527, Strength Tests of Thin-Walled Duralumin Cylinders of Elliptic Section, Eugene E. Lundquist and Walter F. Burke.

No. 528, Wind-Tunnel Tests of a Cyclogiro Rotor, John B. Wheatley and Ray Windler.

No. 529, Analysis of a Strut with a Single Elastic Support in the Span, with Applications to the Design of Airplane Jury-Strut Systems. Part I.—Derivation of Formulas, Murray Schwartz; Part II.—Experimental Investigation of Formulas, Reid Bogert.

No. 530, Bending Stresses Due to Torsion in Cantilever Box Beams, Paul Kuhn.

No. 531, Tank Tests of Model 11-G Flying-Boat Hull, J. B. Parkinson.

No. 532, Method of Testing Oxygen Regulators, Harcourt Sontag and E. L. Borlik.

No. 533, The Thermodynamics of Combustion in the Otto Cycle Engine, E. S. Taylor.

No. 534, Principal Effects of Axial Load on Moment-Distribution Analysis of Rigid Structures, Benjamin W. James.

No. 535, The Effect of Depth of Step on the Water Performance of a Flying-Boat Hull Model—N.A.C.A. Model 11-C, Joe W. Bell.

No. 536, The 6ft. 4in. Wind Tunnel at the Washington Navy Yard, G. L. Desmond and J. A. McCrary.

No. 537, A Preliminary Determination of Normal Accelerations on Racing, N. F. Scudder and H. W. Kirschbaum.

No. 538, A General Tank Test of N.A.C.A. Model 11-C Flying-Boat Hull, including the Effect of Changing the Plan Form of the Step, John R. Dawson.

AERONAUTICAL RESEARCH COMMITTEE

Report for the Year 1934-1935.

Technical Reports of the Aeronautical Research Committee, 1933-1934. Vol. I.—Aerodynamics; Vol. II.—Structures, Engines and Instruments, etc.

REPORTS AND MEMORANDA OF THE AERONAUTICAL RESEARCH COMMITTEE

No. 1547, Experimental Investigation of Boundary Layer Flow, L. F. G. Simmons and R. J. M. Payne.

No. 1573, On the Calculation of Stresses in Braced Frame-works, R. V. Southwell and J. B. B. Owen.

No. 1608, Constitution of Magnesium Rich Alloys of Magnesium Nickel (Abstract only), J. L. Haughton and R. J. M. Payne.

No. **1609**, Wind-Tunnel Tests on Bristol Fighter Model with Slotted R.A.F. **34** Section Wings, K. W. Clark.

No. **1611**, The E.M.F. Between Metals in Seater, J. W. Willstrop.

No. **1612**, Consumption Measurements in Flight with Variable Ignition, J. L. Hutchinson and E. Finn.

No. **1613**, Windscreens with Openings, F. B. Bradfield and B. Lockspeiser.

No. **1614**, Abstract. Statistical Measurements of Turbulence in the Flow of Air Through a Pipe, H. C. H. Townend.

No. **1615**, Hot-Wire Type of Instrument for Recording Gusts, L. F. G. Simmons and J. A. Beavan.

No. **1616**, Buckling of a Linked Beam having Strength in Flexure and Shear, R. A. Fairthorne.

No. **1617**, Stiffness Determination in Certain Cantilever Wings, H. Roxbee Cox, J. Hanson and W. T. Sandford.

No. **1618**, Wind-Tunnel Tests on a Model Gloster Troop Carrier, W. G. A. Perring and C. Callen.

No. **1619**, Torsion of a Rectangular Tube with Axial Constraints, D. Williams.

No. **1620**, Transverse Tests on Sand-Cast Aluminium Alloy Bars, C. E. Phillips and J. D. Grogan.

No. **1621**, Cine-Photographic Measurements of Speed and Attitude of Southampton Aircraft when Taking Off and Alighting, A. E. Woodward Nutt and G. J. Richards.

No. **1622**, Flow in the Boundary Layer of Streamline Bodies, H. M. Lyon.

No. **1623**, Effect of Discs on the Air Forces on a Rotating Cylinder, A. Thom.

No. **1624**, Tests on Models of Armstrong Whitworth Four-Engined Monoplane, W. L. Cowley, R. Warden, G. A. McMillan.

No. **1625**, Pressure Distribution on Wings with Ailerons, W. L. Cowley and G. A. McMillan.

No. **1626**, Interference Effect of Surface of Sea on a Flying-Boat, W. L. Cowley and G. A. McMillan.

No. **1627**, Tests of Six Aerofoil Sections at Various Reynolds Numbers in the Compressed-Air Tunnel, E. F. Relf, R. Jones and A. H. Bell.

No. **1628**, Direct Calibration of Compensated Hot-Wire Recording Anemometer, C. Salter and W. G. Raymer.

No. **1629**, Acceleration of Aeroplanes in Vertical Air Currents, H. R. Fisher.

No. **1630**, Application of Matrices to Oscillation Problems, W. J. Duncan and A. R. Collar.

No. **1631**, Forces and Moments on a "Puss Moth" Model, A. S. Batson.

No. **1632**, Steady Flow in the Boundary Layer near the Surface of a Cylinder in a Stream, L. Howarth.

No. **1633**, Reduction of Draughtiness of Open Cockpits, B. Lockspeiser and A. Graham.

No. **1634**, Flow Induced by Jet of Air, H. C. H. Townend.

No. **1635**, Tests of Aerofoils Based Upon R.A.F. **34** Sections, W. L. Cowley and R. Warden.

No. **1637**, Aircraft Vibration, H. Constant.

No. **1638**, Water Pressure on Hull of Boat Seaplane, E. T. Jones and W. H. Davies.

No. **1639**, Wind-Tunnel Wall Interference on Pitching Moments of Large Models in Duplex Tunnel, W. L. Cowley and G. A. McMillan.

No. **1640**, The Aileron Power of a Monoplane, A. G. Pugsley and H. Roxbee Cox.

No. **1641**, Cooling of an Air-Jacketed Engine, A. S. Hartshorn.

No. **1642**, Whirling-Arm Experiments on Lateral Stability, A. S. Halliday and C. H. Burge.

No. **1643**, Approximate Method of Determining Aerodynamic Loading on Wings of Monoplane, A. G. Pugsley.

No. **1644**, Effect of Mass Distribution on Spinning Equilibrium, S. B. Gates and R. B. Francis.

No. **1645**, Report on "Puss Moth" Accidents, Accidents Investigation Sub-Committee.

No. **1646**, Hydrodynamic Forces and Moments on a Simple Planing Surface and on a Flying-Boat Hull, W. G. A. Perring and L. Johnston.

No. **1647**, The Influence of Pickling on the Fatigue Strength of Duralumin, H. Sutton and J. Taylor.

No. **1648**, Reaction on a Wing Whose Angle of Incidence is Changing Rapidly (Wind-Tunnel Experiments with a Short Period Recording Balance), W. S. Farren.

No. **1649**, Wall Interference and Depth Effect in the R.A.E. Seaplane Tank and Scale Effect Tests on Hulls of Three Sizes, L. P. Coombes, D. W. Bottle, W. G. A. Perring and L. Johnston.

No. **1651**, Comparative Measurements of Turbulence by Three Methods, The Staff of the Aerodynamics Department, N.P.L.

No. **1652**, Experiments on Servo-Rudder Flutter, W. J. Duncan, D. L. Ellis and A. G. Gadd.

No. **1653**, Static Stability Tests of Six Full-Scale Twin Flat Seaplanes, R. K. Cushing, A. S. Crouch and W. W. Angell.

No. **1654**, Spinning of a Bristol Fighter Model, including Effect of Wing-Tip Slots and Interceptors, H. B. Irving, A. S. Batson and J. H. Warsap.

No. **1655**, Statistical Measurements of Turbulence, H. C. H. Townend.

No. **1656**, Effect of Wing Setting on Water Performance of Seaplanes, W. G. A. Perring.

No. **1657**, Water Performance of Seaplanes, W. G. S. Perring.

No. **1658**, A New Surface Extensometer, T. W. K. Clarke.

No. **1660**, Slots and Interceptors in Spins, S. B. Gates, H. Irving, R. P. Alston and A. V. Stephens.

No. **1661**, Expanding Passages on Aircraft, F. B. Bradfield.

No. **1662**, Turbulence Tests of the R.A.E. Wind Tunnels, R. Harris and A. Graham.

No. **1663**, Air-Density Effect in Spinning, S. B. Gates and A. Stephens.

REVIEWS

Practical Air Navigation

By Wing Commander J. K. Summers, M.C., R.A.F. Published by Sir Isaac Pitman and Sons, Ltd. Price 2/6.

This book is a short treatise on simple navigation. It has been written for the man who wants to be able to find his way about without having to learn mathematics, and, as such, should be useful to many aircraft pilots.

It is well and clearly written, and the many diagrams should prove most useful, while the chapters on compasses and other instruments give exactly the type of information which is wanted. There is no criticism, courses are referred to as so many degrees T. The meaning of this symbol is unexplained, and although it is possible to deduce its meaning, the reader of a book of this type should not be left to infer anything, he should be told.

At 2s. 6d. the book is excellent value and can be thoroughly recommended.

The War in the Air

Vol. V. By H. A. Jones. Published by the Clarendon Press. Price 17/6.

This volume of the Official History of the War in the Air is of particular interest at the moment when questions of defence against bombing raids are matters which are engaging the attention of the public, as the first part of the book deals with the German raids in the Great War and is a mine of information on the successes and failures and the reasons therefor.

The whole of this part of the book is of outstanding importance and it shows clearly and unmistakably the importance of a co-ordinated plan of defence. The airship raids were made impossible owing to the seriousness of the German losses, and it may be inferred that if the war had continued, the loss of raiding aircraft might have increased to such an extent that the game would not have been worth the candle.

But the defence organisation necessary was colossal. Towards the end of the war there were in Great Britain 469 anti-aircraft guns, 622 searchlights, 258 height-finders, etc., manned by 6,136 officers and men. There were also 376 defence aircraft which absorbed the services of 660 officers, 3,639 men and 315 women; and the fact that this immense mass of equipment had to be diverted from the fighting fronts to purely defensive purposes hampered our conduct of the war. It would be pertinent to enquire what equipment of this nature exists to-day ready for immediate use.

In any future war the attack will have the advantage of much faster aeroplanes with a much greater range and load-carrying capacity, but the quality of the bombs and of the explosives used is not likely to be better. It is also probable that the weight of individual bombs will not be increased, as projectiles of about 700lbs. weight were dropped on London during the war. The greater speed of the attacking aircraft will be neutralised to some extent by the greater speed of the defenders, but the difficulties of the English weather will remain. The conclusion seems to be that active defence is of the greatest importance.

The rest of the book deals with the fighting in the East, and the most notable feature of the narrative is the epic struggle of the Royal Air Force using,

generally, inferior equipment to that of the enemy. For while it was our policy to use in the minor war theatres equipment which was too antiquated for use in Europe, the Germans seem to have sent a few of their latest types to every front. Hence, it happened that a small number of German aircraft were able to carry out their programme unmolested at a height or a speed beyond the capacities of our machines, and the conclusion is inevitable that in no other branch of warfare is it so important to possess equipment equal to or better than that belonging to the enemy.

This volume is a worthy successor to the previous volumes, and is packed with vital information on air matters. It is to be hoped that those who sometimes seek to inform the public on air defence matters will read this book carefully beforehand. Many preconceived ideas will be found to be erroneous and the risks and dangers will be seen in their proper perspective.

Aerodynamic Theory

Vol. V. W. F. Durand, Editor-in-Chief. Published by Julius Springer, Berlin. Price 15 mks. (Ausland precis.)

This is the fifth volume of the series of monographs on the general subject of Aerodynamical Theory, published under the auspices of the Guggenheim Fund for the Promotion of Aeronautics. This particular volume contains two papers only, the first, by Prof. B. Melvill Jones, on the "Dynamics of the Aeroplane," the second, by L. V. Kerber, on "Airplane Performance."

The first paper contains a particularly clear discussion on the theory of the stability of aeroplanes, written in a way which may lead to this matter receiving more attention at the hands of designers than has been the case hitherto. In many directions Prof. Jones has suggested methods of simplifying the equations, and it is possible that he has made the method one which is capable of being used in the drawing office. A point of interest in the paper is his reference to Dr. Lanchester's phugical curves, which are still, apparently, the only practical method of calculating possible flight paths, though they refer, of course, to an idealised aeroplane.

Mr. Kerber's article on "Airplane Performance" is one of immediate and practical importance. He analyses and describes five different methods of calculating the performance of an aeroplane, and his paper on this subject is likely to become a classic. All experienced designers have their own methods of design calculations which reflect the result of their design experience, but they will find here short cuts and simplifications which should be universally applicable. There are at the end of the article a number of estimates of the limits of aeroplane performance, based on present-day limitations, which are of interest. They probably represent feats which are just beyond the bounds of possibility to-day, but which should certainly be possible in a year or two. He considers that a maximum speed of 474 miles an hour, a climb of 11,900ft. per minute, an absolute ceiling of 53,000ft., a range of 14,700 miles, and a duration of 214 hours to be possibly within the powers of specially designed aeroplanes.

It should be noted in this volume, and in others of the series, that the absolute coefficients used by English authors are half the value of those used by Americans. Is it not possible for this discrepancy to be removed by mutual agreement between the various countries concerned?

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

JANUARY, 1935

The New Year

The President and Council wish all members, at home and overseas, a very happy and prosperous New Year.

Assistant to the Secretary

The Council invite applications for the post of an Assistant to the Secretary. Application in the first place must be made in writing addressed to the Secretary and marked "Personal." Applicants should state their age and qualifications. Preference will be given to a young man with some knowledge of aeronautics and engineering. The appointment will be for a probationary period, with a view to a permanency, at a salary of £3 a week.

Meeting of Council

A Meeting of Council was held in the offices of the Society on December 11th when the following members were present:—

Lieut.-Colonel J. T. C. Moore-Brabazon (President) in the chair; Major J. S. Buchanan, Mr. R. S. Capon, Mr. E. C. Gordon England, Mr. A. H. Hall, Mr. S. Scott-Hall, Professor F. T. Hill, Mr. J. E. Hodgson (Honorary Librarian), Major D. H. Kennedy (Honorary Treasurer), Mr. M. Langley, Mr. W. O. Manning, Major R. H. Mayo, Mr. W. P. Savage, Mr. O. E. Simmonds, Mr. H. E. Wimperis (Vice-President) and Mr. L. A. Wingfield (Solicitor).

Among the business discussed was the following:—Report of the Finance Committee; Report of the Grading Committee; Chairmanship of the Lectures Committee; the Wilbur Wright Lecture; the Akroyd Stuart Memorial Prize Award.

Lectures

The attention of members is drawn to the following lectures:—

"Aerodrome Design," by Sir Leopold H. Savile, K.C.B., M.Inst.T., before the Institute of Transport, on January 14th, 1935, at 5.30 p.m., in the Lecture Theatre of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2.

"Progress in Aviation Lighting," by Mr. H. N. Green, before the Illuminating Engineering Society on Tuesday, March 12th, 1935, at 6.30 p.m., in the Lecture Theatre of the Institution of Mechanical Engineers, Storey's Gate, St. James's Park, S.W.1.

Members of the Society are invited to attend both these lectures. Advance copies of the papers will be sent to those members desiring them and those wishing to take part in the discussion on either paper should communicate with the Secretary of the body concerned.

Leverhulme Research Fellowships, 1935

Application is invited for (1) Fellowships or (2) Grants in aid of research. The Fellowships or grants are intended for senior workers who are prevented from carrying out research work by routine duties or pressure of other work.

The duration of the grants will not normally extend over more than two years and the amount will depend on the nature of the research and the circumstances of the applicant. Any subject which may add to human knowledge may be proposed for a Fellowship, but preference is given to subjects in which other provision for research is inadequate.

Forms of application may be obtained from the Secretary, Dr. L. Haden Guest, Leverhulme Research Fellowships, Union House, St. Martin's-le-Grand, E.C.1.

Applications must be received on or before 1st March, 1935. Awards will be announced in July and the Fellowships or Grants will date from September 1st, 1935.

Akroyd Stuart Memorial Prize

The Report of the Referees on the Akroyd Stuart Memorial Prize paper was considered by the Council at their meeting on December 11th, 1934, and it was decided that a special award of 25 guineas should be made to Mr. E. Chatterton for his paper on "The Origin and Development of the Heavy Oil Engine."

Members' Subscriptions

Members are reminded that their annual subscriptions become due on January 1st. Cheques should be sent to the Secretary at 7, Albemarle Street, W.1.

Acknowledgments

The Council acknowledge with grateful thanks the gift of lantern slides from Dr. W. H. Hatfield, Air Commodore J. A. Chamier and Captain J. Durward; copies of Notes on the Interpretation of Aeroplane Photographs in Mesopotamia and Notes on Aerial Photography from Captain J. Durward; copies of lectures by Professor M. Kondo presented by the author.

Forthcoming Events

January 3rd.—Lecture before the Yeovil Branch on "Compression Ignition Engines," by Mr. A. H. R. Fedden, M.B.E., M.I.A.E., M.S.A.E., F.R.Ae.S.

January 3rd.—Lecture before Gloucester and Cheltenham Branch on "High Duty Alloys," by Mr. W. C. Devereux, A.F.R.Ae.S.

January 7th.—Lecture before the Society on "Imperial Air Routes," by Mr. C. F. Snowden Gamble, in the Lecture Theatre of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C., at 6.30 p.m.

January 17th.—Lecture before the Coventry Branch on "The Autogiro," by Senor Juan de la Cierva, F.R.Ae.S.

January 17th.—Lecture before the Yeovil Branch on "Small Oil Engines for Road Transport," by Mr. H. O. Farmer, B.Sc., M.I.A.E.

January 22nd.—Lecture to the Junior Imperial League, Welling, by Mr. E. W. Roberts, M.Sc.

January 24th.—Lecture before the Gloucester and Cheltenham Branch on "The Autogiro," by Senor Juan de la Cierva, F.R.Ae.S.

January 26th.—Lecture to Herne Bay College, by Mr. E. W. Roberts, M.Sc.

January 28th.—Lecture to Nottingham High School, by Mr. G. R. Irvine, A.M.I.Ae.E.

January 28th.—Lecture to Itchen Secondary School, by Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S., M.I.Mech.E., M.I.N.A.

January 29th.—Lecture to Northampton Town and County School, by Mr. G. R. Irvine, A.M.I.Ae.E.

January 29th.—Lecture to Epsom College, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

January 29th.—Lecture to King Edward VI School, by Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S., M.I.Mech.E., M.I.N.A.

January 30th.—Lecture to Upton College, by Mr. E. W. Roberts.

January 31st.—Lecture to Peter Symond's School, Winchester, by Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S., M.I.Mech.E., M.I.N.A.

January 31st.—Lecture before the Yeovil Branch on "The Autogiro," by Senor Juan de la Cierva, F.R.Ae.S.

January 31st.—Lecture before the Gloucester and Cheltenham Branch on "Airport Development," by Squadron Leader Nigel Norman, A.F.R.Ae.S.

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

FEBRUARY, 1935

Election of Council

Attention is drawn to Rules 68-85 regulating the constitution of the Council and in particular to Rules 79 and 81, which read as follows:—

RULE 79.—One half of the Council (excluding the President and the Immediate Past-President if a Member of Council) shall retire annually. The members who shall retire shall be those longest in office, except as provided in Rule 85. Retiring Members of Council who have served two terms in succession (four years) shall not be eligible for re-election until the next annual election, when they will be eligible.

RULE 81.—Nominations of candidates for election to the Council must be received by the Secretary not less than twenty-one days before the Annual General Meeting, with an intimation in writing by the candidates that they are willing to serve. Nominations must be signed by one supporter and two seconders, who must be each entitled to vote in the R.Ae.S.I.

Nomination forms may be obtained from the Secretary.

Under Rule 105 the Annual General Meeting is held at some convenient date before the end of March of each year, so that nominations must be received during the first week in March.

Council Meeting

A Meeting of Council was held on Tuesday, January 8th, 1935, in the Offices of the Society.

Present: Mr. C. R. Fairey (Past-President) in the chair. Captain P. D. Acland, Mr. R. S. Capon, Mr. E. C. Gordon England, Mr. A. H. Hall, Mr. F. T. Hill, Major D. H. Kennedy (Honorary Treasurer), Mr. M. Langley, Mr. W. O. Manning, Mr. D. R. Pye, Mr. S. Scott-Hall, Mr. O. E. Simmonds and Mr. L. A. Wingfield (Solicitor).

Among the business transacted was the following:—The Report of the Finance Committee; the Report of the Grading Committee; Award of the Seagrave Trophy; Joint Lectures; Representatives on the Aerodromes Advisory Board.

Assistant to the Secretary

Mr. William Rea McWilliam has been appointed Assistant to the Secretary.

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on January 8th, 1935:—

Associate Fellows.—Richard Meredith Alcock, Jack Glover, Harold Cecil Smith, Herbert William Victor Steventon, Norman Sykes, Frederick William Westley, Will Walter White.

Associate Members.—Percy William Nunn, Charles Henry Sparkes.

Associates.—Edward Dunham Hall, Sydney Walter Slaughter.

Students.—Ronald Merriman Barry, Alan Coatsworth Brown, Carl Robert Chronander, John Hunter Coghlan, Francis William Fielding, Herbert Fillingham, Ronald Ogilvy Maurice Graham, Frank Jefferson Horn, Shiv Parkash Kathuria, Edward Peter Maynard Keeling, Walter Frederick Locke, Patrick Peek Robertson.

Companion.—Vicomte de Sibour.

Associate Fellowship and Associate Membership Examinations

The next Examinations will be held at 7, Albemarle Street, W.1, on Thursday and Friday, May 16th and 17th. Application forms, obtainable from the Secretary, should be returned completed, with entrance fees, not later than March 15th, 1935. Applications received after that date will not be considered valid.

Subscriptions

Members are reminded that their subscriptions were due on January 1st, 1935. The Council hope that every member will make every effort to pay his subscription as early as possible. The rates are:—

	Home.			Abroad.		
	£	s.	d.	£	s.	d.
Fellow	4	4	0	3	3	0
Member	4	4	0	3	3	0
Associate Fellow	3	3	0	2	2	0
Associate Member	3	3	0	2	2	0
Associate	*2	2	0	*2	2	0
Student	1	1	0	1	1	0
Companion	2	2	0	2	2	0
Founder Member	2	2	0	2	2	0

*£1 1s. 0d. without Journal.

Acknowledgments

The Council gratefully acknowledge a set of back numbers of the Journal from Mr. H. J. Mackintosh and Mr. J. Zeidenfeld; publications, lantern slides and a film from the Society of British Aircraft Constructors; "The Aeronautical Ground Engineers' Licences, A, B, C, D and X," by Captain S. L. Collins from the Author.

Endowment Fund

The Council gratefully acknowledge the gift of One Guinea towards the Endowment Fund from Mr. A. J. Henington, Associate Member.

Membership Badges

For those members of the Society who wish to have them, a badge has been prepared. The badge shows the symbols of the Society, the peregrine and balloon, in finely chased gilt on a blue enamel background, surrounded by a royal blue border on which appears the lettering "The Royal Aeronautical Society, 1866." The badges are hand made with the greatest care so that they will always retain their original appearance, and it is hoped that members will wear them on all suitable occasions.

Members of the Society may obtain badges from the Offices at 7, Albemarle Street for wearing in the lapel of the coat, price 5s. 3d. post free.

Forthcoming Events

February 1st.—Lecture before the Scientific Society of Wakefield Grammar School, by Mr. G. C. F. Ely.

February 2nd.—Lecture before Eastbourne College, by Mr. G. R. Irvine, A.M.I.Ae.E.

February 6th.—Lecture to the Senior Scholars of Bilston Education Committee, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

February 8th.—Lecture before the Society, by Mr. W. C. Clothier, M.Sc., on "Ice Formation in Carburettors," at 6.30 p.m., in the Lecture Theatre of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2.

February 8th.—Lecture before the City of Oxford High School for Boys, by Mr. A. F. Houlberg, A.M.I.Ae.E.

February 9th.—Lecture before Highgate School, by Mr. H. T. Winter, Founder Member.

February 14th.—Lecture before the Gloucester and Cheltenham Branch, by Mr. H. J. Pollard, A.F.R.Ae.S., on "Metal Construction."

February 20th.—Lecture before Wrekin College, by Major T. M. Barlow, F.R.Ae.S.

February 20th.—Lecture before Willaston School, Nantwich, by Mr. G. R. Irvine, A.M.I.Ae.E.

February 21st.—Lecture before the Woolwich Engineering Society, by Mr. R. A. Wilmshurst.

February 21st.—Lecture before King's School, Chester, by Mr. G. R. Irvine, A.M.I.Ae.E.

February 21st.—Lecture before the Coventry Branch, by Major H. N. Wylie, B.Sc., M.B.E., F.R.Ae.S.

February 21st.—Lecture before the Westland Aircraft Society (Yeovil Branch, R.Ae.S.), by Mr. E. F. Relf, A.R.C.Sc., F.R.Ae.S., on "Turbulence."

February 22nd.—Lecture before the Society, by Mr. L. P. Coombes, B.Sc., A.C.G.I., on "Research in the R.A.E. Tank," at 6.30 p.m., in the Lecture Theatre of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2.

February 22nd.—Lecture before Durham School, by Dr. E. G. Richardson, Companion.

February 22nd.—Lecture before Mostyn House School, by Mr. G. R. Irvine, A.M.I.Ae.E.

February 28th.—Lecture before the Gloucester and Cheltenham Branch, by Dr. L. Aitchison, on "Magnesium Alloys."

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

MARCH, 1935

Annual General Meeting

NOTICE IS HEREBY GIVEN THAT THE ANNUAL GENERAL MEETING of the Royal Aeronautical Society, with which is incorporated the Institution of Aeronautical Engineers, will be held on Tuesday, March 26th, 1935, at 6.30 p.m., at the Offices of the Society, 7, Albemarle Street, London, W.1.

AGENDA.

1. To receive and deliberate upon the Report of the Council on the state of the Society, and the Balance Sheets of Aerial Science, Ltd., and Aeronautical Trusts, Ltd., as printed in the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY, with which is incorporated the Institution of Aeronautical Engineers, for March, 1935.
2. To receive the names of those elected to fill the vacancies on the Council for the years 1935-1937.
3. To elect the Auditors for the ensuing year for Aerial Science, Ltd., and Aeronautical Trusts, Ltd.
4. To consider any other business.

Special General Meeting

NOTICE IS HEREBY GIVEN THAT A SPECIAL GENERAL MEETING, under Rule 108, of the Royal Aeronautical Society, with which is incorporated the Institution of Aeronautical Engineers, will be held on Tuesday, March 26th, 1935, immediately following the conclusion of the Annual General Meeting, at the Offices of the Society, 7, Albemarle Street, London, W.1.

AGENDA.

1. To consider the following proposals put forward by the Council for alterations of the Rules:—

RULE 105.

That a full stop should be placed after the words " for the ensuing year," that the words " and to consider any other business of which proper notice has been given in calling the meeting " be deleted and the words " Special business may only be considered at a Special General Meeting " be added.

RULE 108A.

The Council put forward the proposal that a new Rule should be added between the present Rules 108 and 109 to read as follows:—

> " Not less than fourteen clear days' notice shall be given of any Annual General Meeting or Special General Meeting, and the notice convening the meeting shall state the nature of the business to be transacted, and in the case of a Special General Meeting shall set out the resolutions to be considered thereat."

RULE 111.

The Council propose that the following shall be added to the present Rule:—

"Where any special resolution intended to make a change in these Rules is proposed at a Special General Meeting and an amendment to such resolution is proposed, seconded and carried by a two-thirds majority of those present, the Chairman of the meeting shall call for a postal vote.

"An entry in the Minutes by the Chairman on the result of a voting by a show of hands shall be conclusive evidence thereon."

Election of Council

Attention is drawn to Rules 68-85 regulating the constitution of the Council and in particular to Rules 79 and 81, which read as follows:—

RULE 79.—One half of the Council (excluding the President and the Immediate Past-President if a Member of Council) shall retire annually. The members who shall retire shall be those longest in office, except as provided in Rule 85. Retiring Members of Council who have served two terms in succession (four years) shall not be eligible for re-election until the next annual election, when they shall be eligible.

RULE 81.—Nominations of candidates for election to the Council must be received by the Secretary not less than twenty-one days before the Annual General Meeting, with an intimation in writing by the candidates that they are willing to serve. Nominations must be signed by one supporter and two seconders, who must be entitled to vote in the R.Ae.S.I.

Nominations of candidates for election to the Council must be received by the Secretary on or before Tuesday, March 5th, 1935.

Council Meeting

A Meeting of the Council was held on Tuesday, February 12th, 1935.

Present: In the chair, Lieut.-Colonel J. T. C. Moore-Brabazon (President); Captain P. D. Acland, Mr. E. C. Gordon England, Mr. A. H. Hall, Mr. S. Scott-Hall, Professor F. T. Hill, Major D. H. Kennedy (Honorary Treasurer), Mr. M. Langley, Mr. W. O. Manning, Mr. O. E. Simmonds, Mr. L. A. Wingfield (Solicitor).

Among the business considered was the following:—Report of the Finance Committee; Report of the Grading Committee; Annual Report of the Council for 1934; Symposium on Welding by the Iron and Steel Institute; appointment of representatives at the Joint Lecture with the Institution of Automobile Engineers and other bodies on March 5th; appointment of representatives on a Sub-Committee of the Aeronautical Research Committee; Report of the Rules Committee; date of the Annual General Meeting; date of the proposed Garden Party; suggested alteration of time arranged for the Society's lectures.

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on February 12th, 1935:—

Fellows.—Charles Dempster Breese (from Associate Fellow), Henry Nigel St. Valery Norman (from Associate Fellow).

Associate Fellows.—Richard Meredith Alcock, Kenneth Lenton Boswell, Arnold Cadman Clinton, John Wesley Loader, James Murray, Ivor Jones Rees, Hormusji Motashaw Wadia.

Associate Member.—Cecil Herbert Lucas.

Associates.—Robert Edmond Godefroy Brittain, Robert Charles Cox, Roderick Herbert Barrington Grattan, Lawrence Pilkington Hirsh, Graham Stobart Hook, Horace Charles Luttman, Frank Marsh.

Students.—William Kenneth Chapman, Nicholas Gresham Cooke, James A. Currie, William John Goodey, Denis Simpson Gunning, Dennis Malcolm George Harper, Andrew Keith Hunter, David Mellor Jamieson, Jack Voyna Leslie Kemp, Herbert Leaderman, Edward Loveless, Lawrence Richard Morphew, Norman Francis Newberry, Dennis Ralph Sherwin, John Alfred Sizer, Humphrey Montague Smith, Peter Joseph John Weiss, Philip Gordon Wright, Frederick Thomas Young.

Acknowledgments

The Council wish to gratefully acknowledge the gift of some very interesting lantern slides of stratosphere ascents from the National Geographical Society of America; a complete set of the Journals of the Society for 1934 from Miss Cottrell; and various publications from Major R. H. Mayo.

Journal

Owing to the increasing demand for the Society's Journal many issues are now out of print. The Council would be very grateful if members who have finished with their Journals would kindly return them to the Society. Bound volumes for each year are placed on the Library shelves for the convenience of members so that they are always available for reference at any time.

Aeronautical Books

Many members have suggested it would be a considerable help to them if aeronautical books could be obtained through the Society, as they often find difficulty in obtaining these books locally. The Society is in touch with most publishers of aeronautical books and books will be obtained on request.

Forthcoming Events

March 1st.—Lecture before the Society on "Fuels for Aircraft Engines," by Mr. E. L. Bass, at 6.30 p.m., at the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2.

March 1st.—Lecture before Cannock House School, Eltham, by Mr. R. A. Wilmshurst.

March 2nd.—Lecture before Herne Bay College, by Mr. E. W. Roberts.

March 2nd.—Visit by the Students' Section to the Sperry Gyroscope Company, Limited.

March 5th.—Joint Lecture with the Institution of Automobile Engineers and other bodies on "Cold Pressing and Drawing," by Dr. H. Gough and Dr. Desch, at 7 p.m., at the Royal Geographical Society, Kensington Gore, S.W.7.

March 5th.—Lecture before Birkenhead School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

March 5th.—Lecture before Hillingdon School, by Mr. J. T. Morton, A.M.I.Ae.E.

March 6th.—Lecture before Rossall School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

March 12th.—Joint Lecture with the Illuminating Engineering Society on "Aerodrome Lighting," at 6.30 p.m., at the Institution of Mechanical Engineers, Storey's Gate, S.W.1.

March 14th.—Lecture at Chiswick Public Library, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

March 14th.—Lecture before the Yeovil Branch on "Test Flying," by Mr. H. J. Penrose, A.F.R.Ae.S.

March 14th.—Lecture before the Gloucester and Cheltenham Branch, by Mr. J. E. Hodgson, on "Some Pioneers of the Aeroplane."

March 15th.—Lecture before the Society on "New Developments in the Autogiro," by Senor Juan de la Cierva, F.R.Ae.S., at 6.30 p.m., at the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2.

March 17th.—Lecture before Woodford House School, Birchington, by Mr. E. W. Roberts.

March 19th.—Lecture before the Students' Section of the Society on "Steels Used in Aircraft Construction," by Mr. R. L. Lickley, B.Sc., in the Library, at 7, Albemarle Street, W.1, at 7.0 p.m.

March 21st.—Lecture before Coventry Branch on "Blind Flying and Navigation of Aircraft without External Visibility," by Flight Lieut. H. F. Jenkins.

March 26th.—Annual General Meeting of the Royal Aeronautical Society, at 6.30 p.m., in the Library, at 7, Albemarle Street, London, W.1.

March 29th.—Lecture before the Society by Major G. H. Brackley, D.S.O., D.S.C., F.R.G.S., on "Piloting Commercial Aircraft," at 6.30 p.m., at the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2.

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

APRIL, 1935

Council, 1935-36

There were ten vacancies for the Council in March and fifteen nominations. The following is the Council for 1935-36 as a result of the ballot. Newly elected members are marked with an asterisk.

The new Council 1935-1936 is as follows:—

President:

Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.I.Ae.E., M.P.

Past-President:

Mr. C. R. Fairey, M.B.E., F.R.Ae.S.

Vice-President:

Mr. H. E. Wimperis, C.B.E., M.A., M.I.E.E., F.R.Ae.S.

Council:

Captain P. D. Acland.
*Major T. M. Barlow, M.Sc. (Eng.), M.Inst.C.E., M.I.Mech.E., F.R.Ae.S.
Major J. S. Buchanan, C.B.E., A.M.I.Mech.E., F.R.Ae.S.
*Major G. P. Bulman, O.B.E., B.Sc., F.R.Ae.S.
Mr. R. S. Capon, O.B.E., B.A., F.R.Ae.S.
*Mr. H. Roxbee Cox, Ph.D., D.I.C., B.Sc., A.F.R.Ae.S.
Mr. E. C. Gordon England, F.R.Ae.S.
Mr. S. Scott-Hall, A.C.G.I., M.Sc., D.I.C., A.F.R.Ae.S.
Professor F. T. Hill, F.R.Ae.S., M.I.Ae.E.
*Professor G. T. R. Hill, M.C., M.Sc., F.R.Ae.S.
Captain A. G. Lamplugh, F.R.Ae.S., M.I.Ae.E., M.I.Mech.E., F.R.G.S.
Mr. W. O. Manning, F.R.Ae.S.
Major R. H. Mayo, O.B.E., M.A., Assoc.M.Inst.C.E., F.R.Ae.S.
*Dr. N. A. V. Piercy, Assoc.M.Inst.C.E., M.I.Mech.E., F.R.Ae.S.
Mr. D. R. Pye, M.A., F.R.Ae.S.
Mr. E. F. Relf, A.R.C.S., F.R.Ae.S.
Mr. W. P. Savage, A.M.I.Aut.E., A.F.R.Ae.S.
Mr. O. E. Simmonds, M.A., F.R.Ae.S., M.I.Ae.E., M.P.

Honorary Treasurer:

Major D. H. Kennedy, O.B.E., F.R.Ae.S.

Solicitor:

Mr. Lawrence A. Wingfield, M.C., D.F.C., A.R.Ae.S.I.

Honorary Librarian:

Mr. J. E. Hodgson, Hon. F.R.Ae.S.

Honorary Accountant:

Mr. A. N. D. Smith, F.C.A.

Easter Holidays

The Office will be closed from Friday, April 19th, to Monday, April 22nd, inclusive, for the Easter Holidays.

Garden Party

On Sunday, May 5th, 1935, the President (Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.P.) and Council will hold a Garden Party at Heath Row Aerodrome, the use of which has kindly been given to the Society for the day by Mr. C. R. Fairey, M.B.E., F.R.Ae.S., the Immediate Past-President.

The Garden Party will begin at 2.30 o'clock with a reception by the President and Council, after which members and their guests will have the opportunity of watching a flying display and inspecting aircraft. Among the firms which, at the time of going to press, have promised to send machines, are Airspeed, Armstrong Siddeley, Autogiro Company, Fairey Aviation Company, De Havilland Aircraft Company, Hawker Engineering Company, General Aircraft, Ltd., Hendy Aircraft Company, E. W. Percival Company, Phillips and Powis (Miles Hawk), Pobjoy, Railway Air Services, Short Brothers, Spartan Aircraft and Vickers.

In one of the hangars arrangements are being made to show aircraft engines, instruments and accessories, and a historical exhibition of pictures, photographs, etc. A Reid Reaction apparatus will be available for those members and visitors who wish to test their aptitude for flying.

The President and Council extend a special welcome to ladies at the Garden Party.

Tickets, including tea, are 5/- each. Applications for tickets must be received by May 2nd at the latest.

Corrections

In the paper on " High Speed Aircraft Design," by R. M. Clarkson, published in the March Journal, it was stated that all the photographs were due to the courtesy of *Flight*. Three photographs on pages 225-6 were by courtesy of the *Aeroplane*, one on page 222 by courtesy of Fox Photos, and others on pages 218, 220 and 221 by courtesy of the de Havilland Aircraft Co.

Council Meeting

A Meeting of the Council was held on Tuesday, March 12th, 1935, in the Offices of the Society.

Present: Lieut.-Colonel J. T. C. Moore-Brabazon (President) in the chair; Captain P. D. Acland, Mr. R. S. Capon, Major J. S. Buchanan, Mr. E. C. Gordon England, Mr. A. H. Hall, Mr. S. Scott-Hall, Major D. H. Kennedy (Honorary Treasurer), Mr. M. Langley, Mr. D. R. Pye, Mr. W. O. Manning, Mr. W. P. Savage, Mr. O. E. Simmonds, Mr. H. E. Wimperis (Vice-President).

Among the business transacted was the following:—Confirmation of the Appointment of Representatives on a Sub-Committee of the Aeronautical Research Committee; Presentation of an Illuminated Address to His Majesty King George V on his Jubilee; Report of the Finance Committee; Report of the Grading Committee; Report of the First Meeting of the Sub-Committee of the A.R.C.; arrangements for the Garden Party on May 5th, 1935.

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on March 12th, 1935:—

Associate Fellows.—Ernest Leon Bass, Erico Charles Nicola, John Arthur Parkinson Nidd, Ralph Poole.

Associate Member.—George Reginald Clary.

Associates.—Henry Dixon Arnott (Australian), Frederick Alfred Kent, Hedley Lionel Mauler.

Students.—Lionel Hubert Charles Cranfield, Ian G. Duncan, Charles Peter Graham Engelbach, Attwood James Hobbs, Ian George Hopkinson, Miles Craven Rigby, Alexander Reginald Ward, David Wark.

Companion.—Robert Dudley Morrison.

Subscriptions

Under the Rules, members who have not paid their subscriptions for the current year by April 1st are not entitled to have the Journal sent to them. It is not always possible to send back numbers of the Journal to those who pay their subscriptions some time after April 1st, as many of the Journals go out of print.

The Council wish to thank all those members who have been prompt in paying their subscriptions. By the members supporting the Society in this way it is possible to legislate ahead and make arrangements which effect considerable saving against having to work from month to month.

Income Tax

In response to numerous inquiries with regard to a rebate on Income Tax for their subscriptions, the following is a copy of a letter received from the Principal Inspector of Taxes:—

" Ref. H.R.S. 34/C.I. 4420/63. 18/8/28.

Dear Sir,—Further to your interview with Mr. Stoneley at this office on the 19th July, I am now in a position to inform you that the Board of Inland Revenue will not raise objection to the allowance as an expense for Income Tax purposes of annual subscriptions paid by members who are:—

(i) Assessable under Schedule D of the Income Tax Acts in respect of professional or trading profits, subject to the decision of the Commissioners who make the assessment that such subscriptions are sufficiently closely related to the business carried on; or

(ii) Assessable under Schedule E in those cases only in which continual membership of the Society is an essential condition of the terms of appointment.

Yours faithfully,

(Signed) GEO. WILCOCK,

Principal Inspector of Taxes."

Acknowledgments

The Council acknowledge the following:—Journals for 1934 from Mr. F. P. Walsh, Associate Fellow; Journals for 1925-1928 and magazines from the Aircraft Operating Company; Journals from 1907-1924 from Mr. G. W. Hart, Founder Member; Spy Cartoons from Mr. J. V. Holman, Associate; magazines from the Society of British Aircraft Constructors.

First International Aircraft Exhibition, Milan

An International Aircraft Exhibition will be held in the Sports Palace of Milan from October 12th to October 28th next. Full particulars may be obtained from the General Secretary, Via Domodossoia, Milan.

Honours

Dr. W. H. Hatfield, a Fellow of the Society, has been elected a Fellow of the Royal Society.

Membership Badges

For those members of the Society who wish to have them, a badge has been prepared. The badge shows the symbols of the Society, the peregrine and balloon, in finely chased gilt on a blue enamel background, surrounded by a royal blue border on which appears the lettering "The Royal Aeronautical Society, 1866." The badges are hand made with the greatest care so that they will always retain their original appearance, and it is hoped that members will wear them on all suitable occasions.

Members of the Society may obtain badges from the Offices at 7, Albemarle Street for wearing in the lapel of the coat, price 5s. 3d. post free.

Aeronautical Books

Many members have suggested it would be a considerable help to them if aeronautical books could be obtained through the Society, as they often find difficulty in obtaining these books locally. The Society is in touch with most publishers of aeronautical books and books will be obtained on request.

Forthcoming Events

April 3rd-4th.—Conference on Aviation as an International Problem, at the Caxton Hall, Westminster, S.W.1.

April 5th.—Lecture before Gunnersbury Preparatory School by Mr. G. Waters.

April 6th.—Students' Visit to Napier's Engine Works.

April 15th.—Lecture before the Society by Captain G. de Havilland, C.B.E., F.R.Ae.S., on "Commercial Aircraft," at the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2.

April 16th.—Lecture before the Skybird League, at 3.30 p.m., by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

April 16th.—Lecture before the Students' Section in the Library of the Society, at 7 p.m., on "The International Challenge de Tourisme, 1934," by Mr. W. D. McPherson.

J. Laurence Pritchard, *Secretary*.

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

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MONTHLY NOTICES

MAY, 1935

Library Closing

The Library will be closed on Thursday and Friday, May 16th and 17th, for the Associate Fellowship and Associate Membership Examinations.

Aircraft Conference, 1935

With the support of the Air Ministry, the Council of the Royal Aeronautical Society have been invited to co-operate with the Aeronautical Research Committee in the organisation of an aircraft conference in July, 1935, the object of the conference being to discuss the present position of aeronautical research in relation to the technical problems of the British Aircraft Industry. As the number of persons attending the conference must be limited, admission will be by ticket only.

The proceedings will be private, but an account will be published in the Proceedings of the Society.

Council Meeting

A Meeting of the Council was held in the Offices of the Society on Tuesday, April 9th. The following members were present:—Lieut.-Colonel J. T. C. Moore-Brabazon (President) in the chair; Captain P. D. Acland, Major T. M. Barlow, Major G. P. Bulman, Mr. H. Roxbee Cox, Professor F. T. Hill, Mr. S. Scott-Hall, Captain A. G. Lamplugh, Major R. H. Mayo, Dr. N. A. V. Piercy, Mr. E. F. Relf, Major W. P. Savage, Mr. O. E. Simmonds, Mr. H. E. Wimperis, Mr. L. A. Wingfield (Solicitor) and Major D. H. Kennedy (Honorary Treasurer).

Among the business discussed was the following:—Report of the Finance Committee; Report of the Grading Committee; Air House; Aerodromes Advisory Board; Appointment of Committees and Representatives on Other Bodies.

Wilbur Wright Memorial Lecture

The 23rd Wilbur Wright Memorial Lecture will be delivered by D. W. Douglas, Esq., President of the Institute of Aeronautical Sciences, U.S.A., on the "Developments of the Modern Air Liner."

Mr. Douglas is the well-known designer and constructor of Douglas aircraft. A copy of his lecture will be available, free, to everyone attending the lecture. The lecture itself will be one of interest to non-technical as well as technical people, the technical part being chiefly confined to the printed paper and the non-technical to the spoken lecture. The lecture will be delivered in the Science Museum, South Kensington, on Thursday, May 30th, 1935, and will be followed by a Conversazione.

Conversazione

On Thursday, May 30th, 1935, the Society will hold a Conversazione to mark the end of the Session. By kind permission of the Director, Colonel E. E. B. Mackintosh, D.S.O., the Conversazione will be held in the Science Museum, Aeronautical Section, South Kensington, in the immediate neighbourhood of the many historic aircraft which are housed there, the Wright machine, the first power-driven controlled aircraft to fly; the Vickers Vimy, which made the first crossing of the Atlantic in 1919; and many others.

The programme for the evening is approximately as follows:—

8.30—9 p.m.—Reception by the President, Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.P., and Members of Council.

9.15—10 p.m.—Delivery of the 23rd Wilbur Wright Memorial Lecture by D. W. Douglas, Esq.

10 p.m.—midnight.—Conversazione.

The Secretary of State for Air will be present and many other distinguished people. The President and Council earnestly hope that members and their guests will make every possible effort to attend the most important function of the Society's year, and make it a very real success.

Ladies are specially invited to be present as well as non-members.

During the evening, by kind permission of the Air Council, the band of the Royal Air Force will play.

Tickets for the Reception, Lecture and Conversazione (including buffet) are 5/- each, and an early application should be made for them.

Elections

Fellow.—Alan Theodore Eden Eadon.

Associate Fellows.—Jack Lobley, John Howard Sucksmith.

Associate Members.—S. T. Carpenter, David William Stannard.

Associates.—Dermot Mitchell Egan, George William Wilson.

Students.—Francis Joseph Buller, Peter Nisbet Cunningham, Harold Raymond Footit, Douglas Favel Horne, Alastair Rennoldson Ross, George Peter Hutton Square, Cedric Arthur Cuthbert Stone, Rowland Towers, Charles Lewis Wright.

Companions.—Richard Derwick Winsloe, Roy O'Donnell, John S. Gibbons and Thomas P. Mills.

Lecture Suggestions

In May and June the Council and the Lectures Committee consider the Programme of Lectures for the coming Session. The Council will be very glad to receive suggestions for lectures and will always give them very special consideration, as every effort is made each year to present a programme of lectures which will cover as wide a range as possible and be as helpful as possible. Suggestions should be sent in immediately.

Acknowledgments

The Council acknowledge with grateful thanks the donation of One Guinea towards the Endowment Fund from Mr. J. W. C. Logan, Associate Member.

The following members have very kindly presented the Society with copies of past Journals:—Miss A. D. Betts (Companion), Miss G. Cottrell (Companion), Sir E. Owen Williams, K.B.E. (Associate Fellow).

Unpaid Subscriptions

Members who have not paid their subscriptions are reminded that the Journal very quickly goes out of print and back numbers are not always available when the subscription is paid later in the year.

Forthcoming Events

Sunday, May 5th.—Society's Garden Party at the Great West Aerodrome, near Hayes (Mr. Fairey's Aerodrome), 2—7 p.m.

Thursday, May 16th.—Associate Fellowship and Associate Membership Examination.

Friday, May 17th.—Associate Fellowship and Associate Membership Examination.

Thursday, May 30th.—Wilbur Wright Memorial Lecture and Conversazione. W. D. Douglas, Esq., President of the Institute of Aeronautical Sciences, U.S.A., will lecture on "The Developments and Reliability of the Modern Multi-Engined Liner."

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

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MONTHLY NOTICES

JUNE, 1935

Council Meeting

A Meeting of Council was held on Tuesday, May 14th, 1935, in the Offices of the Society.

Present: Lieut.-Colonel J. T. C. Moore-Brabazon (President) in the chair. Captain P. D. Acland, Major T. M. Barlow, Major J. S. Buchanan, Major G. P. Bulman, Mr. R. S. Capon, Mr. H. Roxbee Cox, Professor F. T. Hill, Professor G. T. R. Hill, Mr. J. E. Hodgson (Honorary Librarian), Major D. H. Kennedy (Honorary Treasurer), Mr. W. O. Manning, Major R. H. Mayo, Dr. N. A. V. Piercy, Mr. D. R. Pye, Mr. H. E. Wimperis.

Among the matters under discussion were the following:—Report of the Finance Committee; Report of the Grading Committee; Report of the Medals and Awards Committee; Lecture Programme for the 1935-1936 Session; Election of President, 1935-1936; Election of Vice-Presidents, 1935-1936; formation of Examinations Committee; proposed British Association for Testing Materials; proposed Air House.

Election of President

Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.I.Ae.E., M.P., was elected President of the Society for the year 1935-1936, at the Council Meeting held on May 14th, 1935.

Election of Vice-Presidents

The following were elected Vice-Presidents of the Society for the year 1935-1936, at the Council Meeting held on May 14th, 1935:—

Mr. H. E. Wimperis, C.B.E., F.R.Ae.S.
Major T. M. Barlow, M.Sc.(Eng.), M.Inst.C.E., M.I.Mech.E., F.R.Ae.S.

Honours

The following honours were announced in the Birthday Honours' List:—

G.C.B. (Military Division):—

Air Chief Marshal Sir Edward Leonard Ellington, K.C.B., C.M.G., C.B.E., *Associate Fellow.*

K.C.B. (Military Division):—

Air Marshal Arthur Murray Longmore, C.B., D.S.O., *Founder Member.*

C.B. (Civil Division):—

Harry Egerton Wimperis, C.B.E., M.A., M.I.E.E., *Vice-President, Member of Council* and *Fellow.*

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on May 14th, 1935:—

Associate Fellows.—Herbert Harry Knight, Hervey Pugh Speake.

Associate Members.—Esmond Allen Gibson, Jack Gurney, Raj Nath Kathju, Stanley Spencer, Hubert Courtney Witts.

Associate.—Bimal Kumar Basu.

Student.—Stuart Claude Etheridge Braund.

Companions.—Baron Von Haersolte, Eric Winthrop Woodruff.

Acknowledgments

The Council gratefully acknowledge the presentation of a very interesting collection of lantern slides from Messrs. the Blackburn Aeroplane and Motor Company, Limited; and of a large collection of slides from Major Buchanan.

Library Closing

The Library will be closed on Saturday afternoons from Saturday, June 22nd, until Saturday, September 21st, both inclusive.

Whitsun Holidays

The Offices of the Society will be closed for the Whitsun Holidays from Saturday, June 8th, to Monday, June 10th, inclusive.

Awards

The following awards were made at a Meeting of the Medals and Awards Committee on May 13th, 1935:—

Society's Silver Medal.—C. C. Walker, Esq., F.R.Ae.S., A.M.Inst.C.E. Major F. B. Halford, F.R.Ae.S.

Simms Gold Medal.—Dr. L. Aitchison, B.Sc., F.I.C.

Taylor Gold Medal.—F. Rodwell Banks, Esq., O.B.E., F.R.Ae.S., A.M.I.Aut.E.

Busk Memorial Prize.—H. Roxbee Cox, Ph.D., D.I.C., B.Sc., A.F.R.Ae.S.

Busk Studentship in Aeronautics

A vacancy has arisen for the Busk Studentship in Aeronautics for the year 1935-36. The studentship is of the value of about £150 and tenable for one year from October 1st. It is open to any man or woman being a British subject and of British descent who has not attained the age of 25 before October 1st next.

Applications should be made for the necessary forms, which should be returned by June 8th, to Professor Melvill Jones, Engineering Laboratory, Cambridge.

J. Laurence Pritchard, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

JULY, 1935

August Bank Holiday

The Offices of the Society will be closed from Saturday, August 3rd, to Monday, August 5th, inclusive.

Council Meeting

A Meeting of the Council was held on Tuesday, June 18th, 1935, in the Offices of the Society.

Present: Lieut.-Colonel J. T. C. Moore-Brabazon (President) in the chair; Captain P. D. Acland, Major T. M. Barlow, Major J. S. Buchanan, Major G. P. Bulman, Mr. R. S. Capon, Mr. H. Roxbee Cox, Mr. S. Scott-Hall, Professor F. T. Hill, Professor G. T. R. Hill, Mr. J. E. Hodgson (Honorary Librarian), Captain A. G. Lamplugh, Mr. W. O. Manning, Dr. N. A. V. Piercy, Mr. O. E. Simmonds, Mr. L. A. Wingfield (Solicitor).

Among the business transacted was the following:—Report of the Finance Committee; Report of the Grading Committee; Report of the Lectures Committee.

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on June 18th, 1935:—

Member.—Arthur William Murphy (from Associate Member).

Associate Fellows.—Donald Raymond Price Amor, Charles Herbert Colvin, Harold Everett Falkner, William Garrow-Fisher (from Companion), Geert Otten, Robert Talbot Youngman.

Associate Members.—Edward Dixie Keen (from Associate), Raymond Harcourt Woodall.

Associates.—Gurbax Singh Chowdhery, Albert Godfrey Gooch (from Student), Ronald Douglas King.

Students.—Clifford Claude Caple, Ian Bowman Fleming, Miss Grace Mary Bruce Quennell, John Anthony Mawson Reid, Stephen Arthur Wathen Thompson, John Powell Walters.

Companion.—Gerald Alexander Fraser Embleton.

Public Schools' Lectures

The Council are arranging for the fifth year in succession to give lectures before the Public Schools and other educational establishments. The success of these lectures depends largely upon the very willing help which members of the Society have given by undertaking to deliver a lecture to one of the schools.

As most members know, these lectures are arranged to give the minimum amount of trouble to the lecturer. Each lecture has 40-50 slides and the lecture itself is written round the slides.

The Council hope that this year, as in the past, members will volunteer to give one of these lectures and will get in touch with the Secretary as early as possible. Where it is possible the preference of a member for any particular school or district will be observed. The following is a list of the lectures:—

1. The History of the Aeroplane.
2. The Aeroplane and its Uses.
3. Seaplanes and Flying Boats.
4. Training Royal Air Force Pilots.
5. How Aeroplanes are Built and Fly.
6. The Imperial Air Routes.
7. A Trip into the Stratosphere.

Acknowledgments

The Council gratefully acknowledge a set of back numbers of the Journal from the Association of Special Libraries and Information Bureaux and a collection of English and foreign aeronautical publications from *The Aeroplane*.

Associate Fellowship and Associate Membership Examinations

The following candidates were successful at the examinations held in May, 1935:—

ASSOCIATE FELLOWSHIP.

A. N. Bray	Pure Mathematics. Strength of Materials and Structures. Design (Aircraft).
D. R. H. Dickinson ...	Applied Mathematics. Strength of Materials and Structures. Theory of Internal Combustion Engines.
J. F. Foss	Strength of Materials and Structures. Aerodynamics.
D. S. Gunning	Pure Mathematics. Strength of Materials and Structures. Aerodynamics.
J. C. Hardman	Pure Mathematics. Aerodynamics.
N. F. Newbery	Applied Mathematics. Strength of Materials and Structures. Theory of Internal Combustion Engines.
J. H. Stevens	Applied Mathematics.
C. O. Vernon	Pure Mathematics. Strength of Materials and Structures. Aerodynamics.
J. E. Walker	Applied Mathematics. Strength of Materials and Structures. Aerodynamics.
F. L. Weatherdon ...	Pure Mathematics. Strength of Materials and Structures. Design (Aircraft).
P. N. Willoughby ...	Aerodynamics.

ASSOCIATE MEMBERSHIP.

H. C. N. Barron ...	Applied Mathematics. Strength of Materials and Structures. Theory of Internal Combustion Engines.
C. R. P. Bizeray ...	Design (Aircraft).
A. St. H. Brock	Strength of Materials and Structures.
E. P. M. Keeling ...	Strength of Materials and Structures.
W. H. Newton	Applied Mathematics. Strength of Materials and Structures. Theory of Internal Combustion Engines.
A. M. Scott	Applied Mathematics. Strength of Materials and Structures. Theory of Internal Combustion Engines.
J. E. Shroff	Strength of Materials and Structures.
P. G. Wright	Applied Mathematics. Strength of Materials and Structures. Theory of Internal Combustion Engines.

J. LAURENCE PRITCHARD, *Secretary*.

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

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MONTHLY NOTICES

AUGUST, 1935

August Bank Holiday

The Offices of the Society will be closed from Saturday, August 3rd, to Monday, August 5th, inclusive.

Elliott Memorial Prize

The Elliott Memorial Prize has been awarded to Sergeant-Apprentice P. Wykeham-Barnes and Sergeant-Apprentice J. A. Pitcairn-Hill, of Halton.

Acknowledgments

The Council gratefully acknowledge the receipt of the following:—From W. O. Manning, Esq., a copy of Le Vol à voile, Paris, 1923, and two slides showing the construction of the Coventry Ordnance biplane, 1912.

Associate Fellowship and Associate Membership Examinations

The next examination will be held in the Offices of the Society in December. The exact date will be announced later. Intending candidates must send in their entry forms by September 30th at the latest.

Additions to the Library

The following books have been added to the Library in the last month:—

Aerodynamik, Volume II, by R. Fuchs, L. Hopf and F. Seewald.

Distortion of Metal Crystals, by C. F. Elam.

International Conference on Physics, London, 1934. Volume II. The Solid State of Matter.

Standard Methods for Testing Petroleum and its Products. Third Edition.

Handbook of the Collections Illustrating Heavier-than-Air Craft. Science Museum.

The Air is Our Concern, by Nigel Tangye.

Complete Book of Aviation.

Report of the Proceedings of the 4th International Congress for Applied Mathematics, Cambridge, 1934.

Our Wings Grow Faster, Grover Loening.

Schools Lectures

The Council wish particularly to thank those members of the Society who have already undertaken to give one or more of the schools lectures on behalf of the Society. The demand for these lectures is considerable and many requests have to be refused. The Council hope that any member who has an opportunity to help by delivering one of these lectures will write to the Secretary. Members are reminded that the lectures are complete in themselves, and are each illustrated with 40-50 slides.

The following is a list of the standard lectures at present prepared:—

1. The History of the Aeroplane.
2. The Aeroplane and its Uses.
3. Flying Boats and Seaplanes.
4. Training R.A.F. Pilots.
5. How an Aeroplane is Made and Flies.
6. The Imperial Air Routes.
7. A Trip into the Stratosphere.

J. Laurence Pritchard, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

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MONTHLY NOTICES

SEPTEMBER, 1935

Lecture Programme

The following lectures have been arranged for the 1935-1936 Session. All lectures will be held at 6 o'clock at the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2.

1935.

October 21st.—" Piloting Commercial Aircraft," by Major H. G. Brackley, D.S.O., D.S.C., F.R.G.S.

November 4th.—" The Prevention of Ice Accretion," by Mr. B. Lockspeiser, M.A.

November 18th.—" Cooling Problems with Particular Reference to the Work of the 24ft. R.A.E. Tunnel," by Dr. G. P. Douglas, M.C., A.F.R.Ae.S.

December 2nd.—" Undercarriage Design," by Mr. G. H. Dowty, M.I.Ae.E., A.F.R.Ae.S.

December 16th.—" Wireless and its Application to Commercial Aviation," by Captain J. M. Furnival, M.B.E., A.F.R.Ae.S.

1936.

January 6th.—" Founders of British Aeronautical Science," by Mr. J. E. Hodgson, Hon.F.R.Ae.S.

January 20th.—" The Theory of Alloy Structures," by Professor W. L. Bragg, F.R.S.

February 3rd.—" Airscrew Development," by Dr. H. C. Watts, M.B.E., Assoc.M.Inst.C.E., F.R.Ae.S.

February 17th.—" The Boundary Layer and Recent Developments," by Professor L. Bairstow, F.R.S., F.R.Ae.S.

March 23rd.—" The Jointing of Materials by Welding," by Mr. R. H. Dobson.

April 20th.—" New Light on the Strengths of Materials Afforded by Modern Physics," by Dr. H. J. Gough, M.B.E., F.R.S., and Mr. W. A. Wood.

Attendance at Lectures

For the coming lecture session visitors will only be allowed to attend lectures on production of a ticket which has been obtained through a member of the Society. Tickets cannot be obtained direct from the Offices of the Society by intending visitors except on the written request of a member.

Refreshments at Lectures

At the request of many members it has been decided to hold the lectures at 6.0 p.m. during the coming session and provide light refreshments (tea, coffee, sandwiches and cakes) at 5.30 p.m. There will be no charge to members for refreshments.

Library

The Library will be re-opened on Saturday afternoons from September 21st. The attention of members is drawn to the following extract from the regulations for borrowing library books:—

> Any book may be consulted in the library and most may be borrowed; but certain books, chiefly rare historical ones and reference books in constant demand, are not allowed out of the library. Such reference volumes as Jane's All the World's Aircraft, Reports and Memoranda, N.A.C.A. Reports and Technical Notes, Year Books, and bound volumes of aircraft papers, may not be borrowed unless there is a duplicate copy.
>
> Particular attention is called to Rule 2 for borrowing books. In no circumstances may a book be kept longer than three weeks.

RULES FOR BORROWING BOOKS.

1. Members may borrow not more than two books at a time.
2. Books are not allowed to be kept by a member, whether wanted by another member or not, longer than three weeks.
3. Books may be borrowed by post upon payment of postage both ways. Books may not, however, be borrowed by post by members living abroad.
4. Members borrowing books do so on the condition that any volume lost or damaged is replaced by them.
5. Any book borrowed must be signed for. Members are not allowed to take books direct from the library.

RULES FOR THE LOAN OF SLIDES.

1. Members may borrow any slides in the Society's collection.
2. Slides may not be borrowed more than one week before they are wanted and must not be kept more than ten days in all.
3. Members are responsible for the safe return of the slides they borrow and undertake to pay the cost of replacement of any slides which are cracked or lost.
4. Slides may be borrowed by post on payment of *registered* postage both ways.

NOTE.—*A set of photographic reproductions of slides may be consulted in the Offices of the Society. The cost of replacement of any slide is* 1*s.* 6*d. Slides can be specially made for members from photographs in the Society's collection for* 1*s.* 6*d. each. A list of slides is available price* 1*s.* 0*d. Special sets of slides and descriptions, suitable for lecture purposes, may be obtained on application.*

Non-members are only allowed to borrow slides on the following conditions:—

1. That a deposit for the full value of the slides is made.
2. That all slides broken or lost are paid for.
3. That, when sent by post, registered postage is paid both ways.
4. That a fee of 5s. 0d. for 40 or any less number of slides be paid.

On the return of the slides so borrowed in good condition the amount deposited will be refunded less the cost of postage and the fee charges.

HOURS OF OPENING.

The Library is open as follows:—

Weekdays	...	9.30 a.m.—5 p.m.
Saturdays	...	9.30 a.m.—12.30 p.m.

During the winter months the Library is also open Saturday afternoons from 2.0 p.m.—5 p.m.

The Library is closed on Bank Holidays and the Saturdays preceding them, and at any other periods which may be fixed by the Council.

Additions to the Library

The following books have been added to the Library in the last month:—

Aeroplane Structures, Second Edition, by A. J. Sutton Pippard and J. Laurence Pritchard.

Instruments, by R. W. Sloley.

Max Immelman, Eagle of Lille, by Franz Immelman.

Visibility in Meteorology, by W. E. K. Middleton.

Relativity, by F. W. Lanchester.

Technical Report of the Aeronautical Research Committee. Volume I, Aerodynamics. Volume II, Structures, Engines and Instruments, etc.

Transfer of Heat and Momentum in the Lowest Layers of the Atmosphere, by A. C. Best.

Report of the Federal Aviation Commission, U.S.A.

Technical Notes of the N.A.C.A., Nos. 525 and 526.

Technical Reports of the N.A.C.A., Nos. 512, 513, 516, 524 and 496.

The Simplex Navigation and Avigation Tables, by J. Carlos Pinto.

Pilot's " A " Licence, 7th Edition, by J. F. Leeming.

The Airman's Year Book, Royal Aero Club.

L'Aeronautique in Pologne, Bogdan J. Kweicinski.

Reports and Memoranda of the A.R.C., Nos. 1573, 1639, 1640, 1642, 1643, 1644, 1646, 1647, 1645, 1648, 1649, 1624, 1625, 1630, 1631, 1632, 1633, 1634, 1635.

Aluminium: Finishing Processes; Welding and Soldering; Sheet Metal Working, and Machining and Forging. British Aluminium Co.

The Modern Diesel, Third Edition, Messrs. Iliffe and Sons, Limited.

Reports of the Aeronautical Research Institute, Tokyo Imperial University, Volume X, Nos. 3-6. (In English.)

Acknowledgments

The Council wish gratefully to acknowledge the gift of books and pamphlets from Squadron Leader E. J. D. Townesend, Associate Fellow; copies of back numbers of the Journal from Miss A. D. Betts, Companion; Journals from " The Aeroplane "; and a set of lantern slides from Imperial Airways.

Forthcoming Events

September 10th.—Council Meeting in the Offices of the Society.

September 26th.—Lecture before the Yeovil Branch (Westland Aircraft Society), by Captain J. Laurence Pritchard, on "The Stratosphere."

October 4th.—Lecture before University College School, by Mr. H. T. Winter.

October 10th.—Lecture before the Yeovil Branch, by Mr. A. C. Hughes, on "Flying over the Empire."

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

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MONTHLY NOTICES

OCTOBER, 1935

Lectures

The Inaugural Lecture will be held on Monday, October 21st, when Major H. G. Brackley, D.S.O., D.S.C., F.R.G.S., will lecture on "Piloting Commercial Aircraft." The lecture will be held in the Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at **6 p.m.** (Please note the new time.) Light refreshments will be served at 5.30 p.m. **Visitors will only be admitted by ticket obtainable through a member of the Society.**

Council Meeting

At a Council meeting held on September 10th, 1935, the following members were elected:—

Fellows.—Hugh Burroughes, Jean Pontremoli.

Associate Fellows.—R. P. Alston, H. C. W. Brewer, W. E. W. Petter, H. W. Sims-White, J. E. Walker, G. H. C. Willins.

Associates.—M. W. Bartlett, S. Bhandari, R. Denton-Samuel, R. Douglas, M. L. Gaine, J. M. Grennen, K. J. Sewell, G. A. Stenning, W. P. Lewis.

Students.—E. E. Blofield, A. H. Emden, W. I. Foster, H. G. Grigg, A. R. B. Nash, F. H. Robertson.

Companions.—J. R. Crean, V. L. Gruberg, N. Irmescu, E. W. C. Wilkins.

Among the business discussed was the following: Report of the Finance Committee; Report of the Grading Committee; Appointment of Representative on the Board of Trustees of the British Gliding Association; Formation of Branches in Portsmouth and Southampton; suggested research work on Fire Prevention; appointment of referees for the R.38 Memorial Prize entries.

Associate Fellowship and Associate Membership Examination

The next Associate Fellowship and Associate Membership examination will be held in the offices of the Society on Tuesday, December 17th and Wednesday, December 18th.

The Library will be closed on those days.

Forthcoming Events

October 4th.—Lecture before University College School, by Mr. H. T. Winter, on "A Trip into the Stratosphere."

October 10th.—Lecture before the Yeovil Branch, by Mr. A. C. Hughes, on "Flying over the Empire."

October 15th.—Lecture before the Students' Section, by Mr. A. Gouge, B.Sc., F.R.Ae.S., on "The Commercial Aspect of the Long-Range Flying Boat," in the Library of the Society at 7, Albemarle Street, at 7 p.m.

October 17th.—Lecture before the Kingswood Grammar School, Bristol, by Mr. W. Brierley, on "Training R.A.F. Pilots."

October 18th.—Lecture before Balshaw's Grammar School, by Captain J. Laurence Pritchard, on "A Trip into the Stratosphere."

October 18th.—Lecture before Durham School, by Mr. J. Bell, on "A Trip into the Stratosphere."

October 21st.—Lecture before the Society by Major H. G. Brackley, D.S.O., D.S.C., F.R.G.S., on "Piloting Commercial Aircraft," in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2., at **6 p.m.** Refreshments at 5.30 p.m.

October 24th.—Lecture before the Yeovil Branch, by Mr. H. Inman, on "Some Industrial Uses of the Oxy-Acetylene Blowpipe in Great Britain."

October 25th.—Lecture before Rutherford College, by Mr. J. Bell, on "A Trip into the Stratosphere."

October 25th.—Lecture before King's School, Rochester, by Mr. C. P. Lipscomb, on "The Imperial Air Routes."

October 26th.—Lecture before Caterham School, by Captain J. Laurence Pritchard, on "A Trip into the Stratosphere."

October 30th.—**Brancker Memorial Lecture,** Institute of Transport. "Air Transport in Great Britain," by Lieut.-Col. F. C. Shelmerdine, C.I.E., O.B.E., A.F.R.Ae.S., at the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at 6 p.m.

October 31st.—Lecture before Imperial Service College, by Lieut.-Commander the Hon. J. M. Southwell, on "The History of the Aeroplane."

November 4th.—Lecture before the Society, by Mr. B. Lockspeiser, M.A., on "The Prevention of Ice Accretion," in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at **6 p.m.**

November 7th.—Lecture before the Yeovil Branch, by Mr. H. J. C. Harper and Flt.-Lieut. F. Kirk, on "Deck-Landing Aircraft."

November 9th.—Lecture before Coatham School, by Mr. J. Bell, on "The Imperial Air Routes."

November 15th.—Lecture before Gillingham County School, by Mr. C. T. Lipscomb, on "A Trip into the Stratosphere."

Brancker Memorial Lecture

The attention of all members is drawn to the first Brancker Memorial Lecture, which will be delivered on October 30th by the Director-General of Civil Aviation, Lieut.-Col. F. C. Shelmerdine, C.I.E., O.B.E., A.F.R.Ae.S., at the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at 6 p.m. Members of the Society will be particularly welcome at the lecture. The subject is: "Air Transport in Great Britain."

Acknowledgments

The Council gratefully acknowledge the gift of slides from the Air League and Imperial Airways.

Additions to Library

The following books have been added to the Library during the month:—

The Hardness of Metal and Its Measurement, by High O'Neill.

Aircraft and Flying, by F. V. Monk and H. T. Winter.

Last Flight, by Barbara Hall.

The Flying Flea ("Le Pou de Ciel"). Translated from the French. Henri Mignet.

Aerodynamic Theory, Volume IV, by W. F. Durand.

A Manual of the Principles of Meteorology, by R. Mountford Deeley.

The Care and Maintenance of Aircraft. Seventh Edition.

International Index to Aeronautical Technical Reports, 1934.

Seaplane Float and Hull Design, by M. Langley.

Practical Performance Prediction of Aircraft, by J. D. Blyth.

Aeroplanes and Engines (Airsense), Second Edition, by W. O. Manning.

Preprinted Papers and Programme of the Aeronautic and Hydraulic Divisions of the American Society of Mechanical Engineers.

The Noral Handbook, Sections A and C. Northern Aluminium Company.

The Automatic Pilot, Smith's Aircraft Instruments.

Sefton Brancker, by Norman Macmillan.

Pilot Tex, by Arnold Hagenback.

Some Japanese Balloon Prints, from the collection of Bella C. Landauer.

Summer Thunderstorms, by S. Morris Bower.

Engineering Valves, by A. L. Mellanby.

Transactions of the Institution of Automobile Engineers, 1934.

Proceedings of the Institution of Automobile Engineers, 1934.

Abridgments of Patent Specifications.

Scientific Papers of the Institute of Physical and Chemical Research of Japan.

Bulletin of the Institute of Physical and Chemical Research of Japan.

Journal of the Society of Aeronautical Science of Nippon.

Aircraft Manufacture, by R. McKinnon Wood.

R. and M. No. 1638. Water Pressure on Hull of Boat Seaplane, by E. T. Jones and W. H. Davies.

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

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MONTHLY NOTICES

NOVEMBER, 1935

Council Meeting

A meeting of the Council was held in the Offices of the Society on Tuesday, October 8th, 1935.

Present: Lieut.-Colonel J. T. C. Moore-Brabazon (President) in the chair; Major T. M. Barlow (Vice-President), Major J. S. Buchanan, Major G. P. Bulman, H. Roxbee-Cox, Esq., E. C. Gordon England, Esq., S. Scott-Hall, Esq., Professor F. T. Hill, Professor G. T. R. Hill, Captain A. G. Lamplugh, W. O. Manning, Esq., Dr. N. A. V. Piercy, W. P. Savage, Esq., O. E. Simmonds, Esq.

Among the business discussed was the following:—Report of the Grading Committee; Report of the Finance Committee; Lecture by Dr. S. J. Zand; Proposed Aeronautical Congress in America.

Elections

The following Members were elected at the Meeting of Council held on October 8th, 1935:—

Fellow.—Francis Claude Shelmerdine.

Associate Fellows.—Thomas Stanley Harker, Gustavus McAlpine, Richard Babington Winn.

Associate Members.—Harold Horace Bertram Lewis, Sures Chandra Sen, Willows Septimus Shaw, George Frederick Strand.

Associates.—Frederick Beach, Robert Dudley Morrison, Ronald Windle Potts, Reginald George Robertson.

Students.—Sydney Joseph Cox, Henry Aldyn Cra, Robert Terence Elmes, Edward Reginald Davidson, Harry Gonnell Fox, Edwin William John Gray, Vernon Arthur Moore Hunt, Alexander Myles Jardine, Tek Send Li, Harold George Litchfield, Ronald Maitland, Edward Ogden, Austin Rice, Reginald William Macer Sennitt.

Lecture Dinners

As in previous years, the Royal Aero Club are arranging a late dinner for those who attend lectures of the Society. These dinners have been fixed at 2s. 6d. and members of the Society will be made honorary members of the Royal Aero Club for those evenings. It is hoped that as many members of the Society as possible will take advantage of the facilities offered by the Royal Aero Club, whose address is 119, Piccadilly, W.1. Telephone: Grosvenor 1246-7-8.

Armourers and Brasiers' Company Research Fellowship in Aeronautics

The Armourers and Brasiers' Company are offering a Fellowship of £300 per annum, for two years, for Research in connection with Aeronautics.

Applications must be sent before November 30th, 1935, to the Clerk, Armourers' Hall, 81, Coleman Street, E.C.2, from whom forms of application and particulars of the Fellowship can be obtained.

Acknowledgments

The Council gratefully acknowledge back numbers of the Journal from Mr. W. G. Kentfield (Associate Member), Mr. T. B. Ringwood (Associate Member) and Miss G. Cottrell (Companion).

Lectures

The next lecture will be held on Monday, November 4th, when Mr. B. Lockspeiser, M.A., will lecture on "The Prevention of Ice Accretion." The lecture will be held in the Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at **6.0 p.m.** (Please note the new time.) Light refreshments will be served at 5.30 p.m. *Visitors will only be admitted by ticket, obtainable through a member of the Society.*

It would be greatly appreciated if members would express a definite opinion in writing to the Secretary about the new arrangements for refreshments before the lectures and the new time, 6.0 p.m. instead of 6.30 p.m.

Additional Lecture

The Council are glad to be able to announce that Dr. S. J. Zand has agreed to lecture before the Society on Monday, November 25th.

Dr. Zand is well known for the work he has been doing on lessening noise in aircraft, and upon which he has already obtained remarkable results. The title of the lecture will be "Sound Proofing of Aircraft," and it will be illustrated with a number of slides.

The lecture will be held in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at 6.0 p.m. Light refreshments will be served between 5.30 and 6.0 p.m. to members and their friends.

Additions to the Library

Reports and Memoranda of the Aeronautical Research Committee:—

No. 1638. Water Pressure on Hull of Boat Seaplane, by E. T. Jones and W. H. Davies.

No. 1641. Cooling of an Air-Jacketed Engine, by A. S. Hartshorn.

No. 1651. Comparative Measurements of Turbulence by Three Methods, by the Staff of the Aerodynamics Department, N.P.L.

No. 1652. Experiments on Servo-Rudder Flutter, by W. J. Duncan, D. L. Ellis and A. G. Gadd.

No. 1653. Static Stability Tests of Six Full-Scale Twin Flat Seaplanes, by R. K. Cushing, A. S. Crouch and W. W. Angell.

No. 1654. Spinning of a Bristol Fighter Model, Including Effect of Wing Tip Slots and Interceptors, by H. B. Irving, A. S. Batson and J. H. Warsap.

No. 1655. Statistical Measurements of Turbulence, by H. C. H. Townend.

No. 1656. Effect of Wing Setting on Water Performance of Seaplanes, by W. G. A. Perring.

No. 1657. Water Performance of Seaplanes, by W. G. S. Perring.

No. 1658. A New Surface Extensometer, by T. W. K. Clarke.

No. 1660. Slots and Interceptors in Spins, by S. B. Gates, H. B. Irving, R. P. Alston and A. V. Stephens.

No. 1661. Expanding Passages on Aircraft, by F. B. Bradfield.

No. 1662. Turbulence Tests of the R.A.E. Wind Tunnels, by R. G. Harris and A. Graham.

No. 1663. Air Density Effect in Spinning, by S. B. Gates and A. V. Stephens.

Technical Reports of the N.A.C.A. :—

No. 511. The Effect of Baffles on the Temperature Distribution and Heat Transfer Coefficients of Finned Cylinders, by Oscar W. Schey and Vern. G. Rollin.

No. 514. The Measurement of the Field of View from Airplane Cockpits, Melvil N. Gough.

No. 515. Full-Scale Wind Tunnel Tests of a PCA-2 Autogiro Rotor, by John B. Wheatley and Manley J. Hood.

No. 519. Spinning Characteristics of Wings I—Rectangular Clark Y Monoplane Wing, by M. J. Bamber and C. H. Zimmerman.

No. 521. An Analysis of Longitudinal Stability in Power-off Flight with Charts for Use in Design, by Charles H. Zimmerman.

No. 523. The Influence of Wing Setting on the Wing Load and Rotor Speed of a PCA-2 Autogiro as Determined in Flight, by John B. Wheatley.

No. 525. Some Effects of Injection Advance Angle, Engine Jacket Temperature, and Speed on Combustion in a Compression-Ignition Engine, by A. M. Rothrock and C. D. Waldron.

No. 526. Noise from Two-Blade Propellers, by E. Z. Stowell and A. F. Deming.

No. 527. Air Flow in a Separating Laminar Boundary Layer, by G. B. Schubauer.

No. 531. The Effect of Water Vapour on Flame Velocity in Equivalent CO-O_2 Mixtures, by Ernest F. Fiock and H. Kendall King.

No. 532. The Soap-Bubble Method of Studying the Combustion of Mixtures of CO and O_2, by Ernest F. Fiock and Carl H. Roeder.

Technical Notes of the N.A.C.A. :—

No. 527. Strength Tests of Thin-Walled Duralumin Cylinders of Elliptic Section, by Eugene E. Lundquist and Walter F. Burke.

No. 528. Wind Tunnel Tests of a Cyclgiro Rotor, by John B. Wheatley and Ray Windler.

No. 529. Analysis of a Strut with a Single Elastic Support in the Span, with Applications to the Design of Airplane Jury-Strut Systems.
Part I.—Derivation of Formulas, by Murray Schwartz.
Part II.—Experimental Investigation of Formulas, by Reid Bogert.

No. 530. Bending Stresses Due to Torsion in Cantilever Box Beams, by Paul Kuhn.

No. 531. Tank Tests of Model 11-G Flying Boat Hull, by J. B. Parkinson.

No. 532. Method of Testing Oxygen Regulators, by Harcourt Sontag and E. L. Borlik.

No. 533. The Thermodynamics of Combustion in the Otto Cycle Engine, by E. S. Taylor.

No. 534. Principal Effects of Axial Load on Moment-Distribution Analysis of Rigid Structures, by Benjamin W. James.

No. 535. The Effect of Depth of Step on the Water Performance of a Flying Boat Hull Model, N.A.C.A. Model 11-C, by Joe W. Bell.

No. 536. The Six-foot—Four-inch Wind Tunnel at the Washington Navy Yard, by G. L. Desmond and J. A. McCrary.

No. 537. A Preliminary Determination of Normal Accelerations on Racing, by N. F. Scudder and H. W. Kirschbaum.

No. 538. A General Tank Test of N.A.C.A. Model 11-C Flying Boat Hull, including the Effect of Changing the Plan Form of the Step, by John R. Dawson.

Report on the Progress of Civil Aviation, 1934.

Journal of the Institute of Metals. No. 1. Volume LVI. 1935.

Metallurgical Abstracts. Series II. Volume I. 1934.

Transactions of the Society of Mechanical Engineers, Japan. Volume I. No. 2.

Jagdstaffel 356, by M. E. Kahnert. Translated by Claud W. Sykes.

Air Gold, by Colin Hope.

An Introduction to the Study of Map Projections. Third Edition. J. A. Steers.

Modern Navigation, by W. Hall.

The Weather Map. H.M.S.O.

Burdwood's Tables. Second Edition.

A Complete Set of Nautical Tables, by J. W. Norie.

Norie's Nautical Tables. Latitude and Longitude Section. J. W. Norie.

Little Book on Map Projection, by William Garnett.

Brown's Signalling, by W. K. Stewart.

Slide Rules and How to Use Them, by Thos. Jackson.

Deviation and the Deviascope, 4th Edition, by Chas. H. Brown.

Questions and Answers in Meteorology. Commonweal Press.

Orfordness Rotating Wireless Beacon. A.M. Pamphlet No. 38.

Regulations Concerning the Minimum Requirements for Air-Worthiness Certificates. I.C.A.N.

Report of the Aeronautical Research Institute, Tokyo Imperial University, No. 125, July, 1935; No. 126, August, 1935; No. 127, August, 1935; Volume X, Nos. 7, 8 and 9.

Scientific Papers of the Institute of Physical and Chemical Research. Volume 27-28, Nos. 585-600.

Bulletin of the Institute of Physical and Chemical Research, Japan. Volume XIV, No. 9.

Applied Elasticity, by J. Prescott.

Forthcoming Events

Nov. 4th.—Lecture before the Society by Mr. B. Lockspeiser, M.A., on "The Prevention of Ice Accretion," in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at **6.0 p.m.**

Nov. 5th.—Lecture before the Bristol Branch on "The Stratosphere," by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

Nov. 7th.—Lecture before the Yeovil Branch, by Mr. H. J. C. Harper and Flight Lieut. Kirk, on " Deck-Landing Aircraft."

Nov. 7th.—Lecture before the Portsmouth Branch, by Mr. R. H. Woodall, A.M.I.E.E., A.M.I.Ae.E., on " Electrical Equipment for Aircraft."

Nov. 7th.—Lecture before Coatham School, by Mr. J. Bell, A.R.Ae.S.I., on " The Imperial Air Routes."

Nov. 15th.—Lecture before Gillingham School, by Mr. C. P. Lipscomb, A.F.R.Ae.S., on " A Trip into the Stratosphere."

Nov. 16th.—Lecture before Stamford School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on " How an Aeroplane is Made and Flies."

Nov. 16th.—Lecture before Ipswich School, by Mr. G. J. Richards, A.F.R.Ae.S., on " Flying Boats and Seaplanes."

Nov. 16th.—Lecture before Berkhamstead School, by Mr. M. Langley, M.I.Ae.E., A.M.I.N.A., on " How an Aeroplane is Made and Flies."

Nov. 16th.—Lecture before Herne Bay College, by Mr. E. W. Roberts, on " Training R.A.F. Pilots."

Nov. 18th.—Lecture before the Society, by Dr. G. P. Douglas, M.C., A.F.R.Ae.S., on " Cooling Problems with Particular Reference to the Work of the 24ft. R.A.E. Tunnel," in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at **6.0 p.m.**

Nov. 19th.—Lecture before the Students' Section, by Mr. P. P. Nazir, A.F.R.Ae.S., on " Tapered Wing Stalling," at 7.0 p.m., in the Library of the Society at 7, Albemarle Street, W.1. Mr. H. E. Wimperis, C.B.E., F.R.Ae.S. (Vice-President), in the chair. The lecture will be illustrated by a film.

Nov. 21st.—Lecture before City of London Freemen's School, by Mr. N. A. Champion, A.M.I.Ae.E., on " A Trip into the Stratosphere."

Nov. 21st.—Lecture before the Rotary Club of Leatherhead, by Mr. N. A. Champion, A.M.I.Ae.E., on " A Trip into the Stratosphere."

Nov. 21st.—Lecture before the Westland Branch, by Mr. H. A. Drane, on " Machine Tools for Small Batch Production."

Nov. 21st.—Lecture before the Portsmouth Branch, by Mr. W. Hackett, on " Tubes and Tube Manipulation."

Nov. 21st.—Lecture before the Coventry Branch, by Lieut. H. Cantrill, on " Carburation and Engine Controls."

Nov. 22nd.—Lecture before St. Edmund's School, Canterbury, by Mr. E. W. Roberts, on " A Trip into the Stratosphere."

Nov. 22nd.—Lecture before the Institute of Fuel, by Mr. Kenneth Gordon, entitled " The Development of Coal Hydrogenation by the Imperial Chemical Industries, Limited," at 6.0 p.m., in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2. Members of the Society are invited to attend. Tickets not required.

Nov. 25th.—Lecture before the Society, by Dr. S. J. Zand, on " Sound Proofing of Aircraft," in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at **6.0 p.m.**

Nov. 26th.—Lecture at Kingston Public Library, by Mr. J. V. Connolly, B.E., A.F.R.Ae.S., on " The Uses of the Aeroplane."

Nov. 26th.—Lecture before the High School, Newcastle, Staffs., by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "A Trip into the Stratosphere."

Nov. 27th.—Lecture before Upton College, by Mr. E. W. Roberts, on "A Trip into the Stratosphere."

Nov. 29th.—Lecture before King's School, Rochester, by Mr. C. P. T. Lipscomb, A.F.R.Ae.S., on "Imperial Air Routes."

Nov. 30th.—Lecture before Woodford House School, Birchington, by Mr. E. W. Roberts, on "A Trip into the Stratosphere."

Dec. 2nd.—Lecture before the Society, by Mr. G. H. Dowty, M.I.Ae.E., A.F.R.Ae.S., on "Undercarriage Design," in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at **6.0 p.m.**

Dec. 4th.—Lecture before St. Olave's School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "Imperial Air Routes."

Dec. 4th.—Lecture before Annfield Plain Schools, by Dr. E. G. Richardson, on "How an Aeroplane is Made and Flies."

Dec. 4th.—Lecture before Germain's Senior Boys' School, by Captain A. B. Fanstone, A.F.C., M.A., A.F.R.Ae.S., on "How an Aeroplane is Made and Flies."

Dec. 5th.—Lecture before the Westland Branch, by Mr. A. Davenport, F.R.Ae.S., on "Aircraft Design and its Practical Application."

Dec. 6th.—Lecture before King's School, Ely, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "How an Aeroplane is Made and Flies."

Dec. 9th.—Lecture before King Edward IV School, by Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S., on "The Imperial Air Routes."

Dec. 10th.—Lecture before Birkenhead School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "A Trip into the Stratosphere."

Dec. 10th.—Lecture before Rossall School, Fleetwood, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "How an Aeroplane is Made and Flies."

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

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MONTHLY NOTICES

DECEMBER, 1935

Examinations and Library Closing

The Library will be closed on Tuesday, December 17th, and Wednesday morning, December 18th, during the Associate Fellowship and Associate Membership Examinations.

Christmas Holidays

The Offices will be closed on Wednesday, December 25th, and Thursday, December 26th, for the Christmas Holidays.

Council Meeting

A Meeting of the Council was held on Tuesday, November 12th, in the Offices of the Society.

Present.—Major T. M. Barlow (Vice-President) in the chair; Captain P. D. Acland, Major J. S. Buchanan, Mr. R. S. Capon, Mr. E. C. Gordon England, Mr. S. Scott Hall, Professor F. T. Hill, Professor G. T. R. Hill, Mr. W. O. Manning, Major R. H. Mayo, Dr. N. A. V. Piercy.

Among the business transacted was the following:—Report of the Finance Committee; Report of the Grading Committee; Time of Starting Lectures; Common Entry Examination; Scholarships in Aeronautics; Lecture on "The Use of Plastic Materials in Aviation."

Elections

The following members were elected at the Council Meeting on November 12th:—

Associate Fellows.—John Allen Rowlatt Jones, David Richmond Hay Surgeoner.

Associates.—Ronald Eric Bishop, Philip Alexander Roby Bremridge, John Martin Freeman, Reginald Frederick Long, Donald McCorquodale, Murzban Ruttonjee Mandviwalla, Maurice Robert Desmond Trewby.

Students.—John White Burman, Leslie Gordon Byrne, Norman Coles, Gerald Claud Crack, John Horace Hamilton Davison, James Charles Floyd, Stanley John Gower French, Thomas Edward Goligher, Ruben Hadekel, Denis Alban James Harben, Leslie Ronald Hordley King, Edward William Lofts, Lionel Pekarksy, Charles Peter Plantin, Wynand Johannes Pretorius, Donald Burnett Rae, William George Savory, Maurice Sydney Spickernell, Lokusatu Heva Sumanadasa, Frederick James Alexander Thompson, David White, Leslie George Whitehead, Charles Harold Wigg.

Companion.—Charles G. K. Browne.

Elliott Memorial Prize

The Elliott Memorial Prize has been awarded to Sergeant/Apprentice D. C. Maybury.

Aeronautical Diaries, 1936

Copies of the Aeronautical Diary, 1936, may be obtained from the Office, price 6/- for the Wallet type, 2s. 6d. for the Refill style with pocket, and 1s. 6d. plain diary with pencil. Postage is 3d. extra on each diary. The Society's crest is on each diary.

Special Lecture

The attention of members is drawn to the Lecture on "The Expanding Aircraft Industry and its Possible Uses for Plastics," on December 12th, at 7.45 p.m., at the British Industries House, Marble Arch, W.1. The lecture is to be held under the auspices of the Institute of the Plastics Industry and members of the Royal Aeronautical Society are invited to attend. Tickets may be obtained on application to the Honorary Secretary, Windsor House, Victoria Street, S.W.1.

Proceedings of the Welding Symposium, 1935

The Organising Committee of the Iron and Steel Institute have made the two bound volumes of the above Proceedings available to Members of the Society at the reduced price of £1 10s. 0d. per set, carriage extra, 1s. in Great Britain; 2s. abroad. The published price is £2 2s. 0d. Copies should be ordered through the Society.

Lecture Times

In response to the request of many members the times of the lectures for the second half of the Session will be at 6.30 p.m. instead of 6.0 p.m. Tea will be served to members from 6.0 to 6.30 p.m. Special attention is drawn to the rule that non-members can only be admitted through a member.

Lecture Programme—Second Half of the Session

The following lectures have been arranged for the Second Half of the 1935-36 Session:—

January 6th.—J. E. Hodgson, Hon. F.R.Ae.S., "Founders of British Aeronautical Science."

January 20th.—Professor W. L. Bragg, F.R.S., "The Theory of Alloy Structures."

February 3rd.—Dr. H. C. Watts, M.B.E., Assoc.M.Inst.C.E., F.R.Ae.S., "Airscrew Development."

February 17th.—Professor L. Bairstow, C.B.E., F.R.S., F.R.Ae.S., "The Boundary Layer and Recent Developments."

March 23rd.—R. H. Dobson, Esq., "The Jointing of Materials by Welding."

April 20th.—Dr. H. J. Gough, M.B.E., F.R.S., and W. A. Wood, Esq., "New Light on the Strength of Materials Afforded by Modern Physics."

All the above lectures will be held in the Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at **6.30 p.m.**

The date and subject of the Wilbur Wright Lecture will be announced shortly.

Additions to the Library

Practical Air Navigation. J. K. Summers.
The War in the Air (with Maps). Volume V. H. A. Jones.
Aerodynamic Theory. Volume V. W. F. Durand.
Repertorium Technicum. Volume IV. Nos. 7 and 8.
Science Reports of the Tokyo Bunrika Daigaku, Section A. Volume II. Nos. 43, 44, 45-46.
Transactions of the Society of Mechanical Engineers, Japan. Volume I. No. 2.
Report of the Aeronautical Research Institute, Tokyo Imperial University. Volume X. No. 10.
Scientific Papers of the Institute of Physical and Chemical Research. No. 584, Nos. 601-602, Nos. 603-606.
Bulletin of the Institute of Physical and Chemical Research.
Some Observations on the Thermal Structure of Cumuliform Cloud. Flt. Lieut. R. G. Veryard.
Notas Para Una Climatologia De Menorca Regimen de Vientos. Jose M. Jansa Guardiola.
Abbreviations to be Used in the Civil Aeronautical Radio Service. Air Publication No. 1529.
Report of the Progress of Civil Aviation, 1934.
The Book of the Aeroplane. J. Laurence Pritchard.
Solder. International Tin Research and Development Council.
Solar Radiation and Weather Studies. C. H. Abbot.
Standard Methods for Testing Petroleum and its Products. Institute of Petroleum Technologists.
The Thermal Structure of the Upper Air Over a Depression during the Indian South-West Monsoon. N. K. Sur.
Heat Resisting Alloys. Mond Nickel Co., Ltd.
Report of the Aeronautical Research Committee, 1934-35.
Proceedings of the Institution of Mechanical Engineers. Volume CXXIX. 1935.

Acknowledgments

The Council acknowledge with grateful thanks the receipt of back Journals from Dr. Merton, Library Books and back Journals from Mr. M. H. Volk, lantern slides from Mr. E. L. Bass, and Library Books from the Air League of the British Empire.

Forthcoming Events

Dec. 2nd.—Lecture before the Society by Mr. G. H. Dowty, M.I.Ae.E., A.F.R.Ae.S., on "Retractable Undercarriages," in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, at **6.0 p.m.**

Dec. 4th.—Lecture before St. Olave's School, by Captain J. Laurence Pritchard, on "The Imperial Air Routes."

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Dec. 10th.—Lecture before Rossall School, Fleetwood, by Captain J. Laurence Pritchard, on " How an Aeroplane is Made and Flies."

Dec. 10th.—Meeting of Council in the Library of the Society, 5.30 p.m.

Dec. 12th.—Lecture before the Institute of the Plastics Industry, on " The Expanding Aircraft Industry and its Possible Uses for Plastics," at 7.45 p.m., at the British Industries House, Marble Arch, W.1.

Dec. 16th.—Lecture before the Society, by Captain J. M. Furnival, M.B.E., A.F.R.Ae.S., on " Wireless and its Application to Commercial Aviation," in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at **6.0 p.m.**

Dec. 17th.—Lecture before the Bristol Branch, by Herr R. Kronfeld, on " Gliding."

Dec. 17th and 18th.—Associate Fellowship and Associate Membership Examinations, in the Library of the Society, at 7, Albemarle Street, W.1.

Dec. 19th.—Lecture before the Coventry Branch, by Captain J. Laurence Pritchard, on " The Stratosphere."

Dec. 19th.—Lecture before the Portsmouth Branch, by Mr. H. J. Pollard, Wh. Ex., A.F.R.Ae.S., on " Metal Construction."

Dec. 19th. Sound Pictures before the Westland Branch by a Representative of the British Thomson Houston Company, Limited, Rugby.

J. LAURENCE PRITCHARD, *Secretary*.